THE PRODUCTIVITY PARADOX: INFORMATION TECHNOLOGY AND PRODUCTIVITY

by

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ABBREVIATIONS

BEA	US Bureau of Economic Analysis
BLS	US Bureau of Labor Statistics
CFT	Capital flow tables
CPI	Consumer price index
DOC	US Department of Commerce
GDP	Gross Domestic Product
GNP	Gross National Product
IP	Information processing - as in “IP equipment and software”
IT	Information technology; also ITC
ICT	Information and communication technology; also IT
JEL	*Journal of Economic Literature*
K	Quantity of capital
KLEMS	Capital (K), labour (L), energy (E), intermediate inputs (M)
L	Quantity of labour
LP	Labour productivity
MFP	Multifactor productivity; see TFP
NIPA	National income and product accounts
NDP	Net domestic product
NNP	Net national product
NRC	National Research Council (US)
OECD	Organisation for Economic Cooperation and Development
PC	Personal computer
Q	Output; see Y
R&D	Research and development
SNA	System of National Accounts

SCB	*Survey of Current Business,* DOC
TCP/IP	Transmission control protocol/internet protocol
TFP	Total factor productivity; see MFP
Y	Output (Y rather than Q is used when output is the same as Income)
Y2K	Year 2000 computer bug; or the Millennium bug
USA	United States of America
WWW	World wide web

SYMBOLS

α	share of capital in total output
β	share of labour in total output

1. CHAPTER 1: PRODUCTIVITY, THE PRODUCTIVITY SLOWDOWN AND THE PRODUCTIVITY PARADOX

1.1. Overview

The introduction is intended to provide a broader context for the analysis of the productivity paradox. Productivity is not regarded as particularly newsworthy in the financial press in South Africa, unlike in the United States of America (USA) and the European Union (EU), where productivity statistics are regularly reported on and debated in the financial media. The introduction thus starts with an examination of the importance of productivity in improving living standards and raising economic growth. The economic significance of productivity is therefore accepted as given, and "proof" of the proposition is not provided here.

The productivity slowdown in the early 1970s in the USA is briefly discussed, and Robert Solow's role in productivity research introduced to contextualise his famous remark that "you can see the computer age everywhere but in the productivity statistics" (Solow 1987:36). The economics of computerisation and the role played by information and communications technology in the productivity slowdown are reviewed. The productivity revival in the mid-1990s and Solow's comments on the revival are discussed.

Chapter 2 examines productivity in the context of technical progress, the Solow "residual" and the aggregate production function.

The analysis and measurement of productivity is discussed in chapter 3. The economic theory of index numbers, such as the construction of index numbers and the index number problem, is explained. The importance of index numbers is stressed because they are the cornerstone of productivity analysis. Many of the measurement issues encountered in the productivity slowdown (as indeed many other areas of economic analysis) are part and parcel of index number theory and practice.

Chapter 4 explores the official productivity statistics as captured in the National Income and Product Accounts (NIPA) of the USA, as well as several related issues, such as productivity definitions, data revisions, and the ICT sector and computers in these accounts.

The productivity paradox is explored more fully in chapter 5 using the analytical tools developed in the previous chapters. An understanding of the economics of computerisation is relevant to the analysis of the productivity paradox. The importance of and relationship between aggregate, industry and firm level studies of productivity, which do not necessarily have results consistent with each other, are considered. The way in which these studies can shed light on the productivity paradox is examined.

The most important and convincing explanations of the productivity paradox, such as the mismeasurement hypothesis, are discussed in chapter 6. Secondary explanations are examined in chapter 7. These are tested and evaluated against the tools developed in previous chapters. The productivity revival in the mid-1990s is discussed against the issues raised during the productivity slowdown period of 1973 to 1995. The chapter also briefly examines the impact of the productivity paradox on economic policy.

Chapter 8 concludes that the productivity paradox remains largely unresolved in the sense that no single explanation can account for the extent of the productivity slowdown between 1973 and 1995. The question of whether the productivity revival in 1995 can be attributed to computerisation and whether it supports the utopian claims of the proponents of the new economy is still a moot point.

1.2. Notes on some of the conventions used in the dissertation

The terms “multifactor productivity (MFP)”, “total factor productivity (TFP)” and the “Solow residual” (or simply “residual”, or “productivity residual”) are used interchangeably, because they are “three names for the same concept” (Fernald & Ramnath 2004:53), even though they are not identical.

The expressions “information technology (IT)” and “information and communications technology (ICT)” are also used interchangeably. The use in the text is usually dictated by what the author being discussed prefers. These terms include computer and communications hardware, as well as the software and related services that are required to operate the hardware (NRC 1994:23, note). More specifically, ICT industries are classified as both manufacturing and service industries. More specifically, ICT *manufacturing* “refer[s] to the manufacturing of telecommunications equipment, computers, semi-conductors, and other electronic equipment”; and ICT *services* “refer to the provision of telecommunications services, computer services and software” (Strydom 2003:1-2).

The terms “technical change or progress” or “technological change or progress” are similar but not identical in meaning and often used synonymously.

The subject of the dissertation is the productivity paradox of information technology; in the literature, the paradox is also referred to variously as the “computer paradox”, the “IT (or ICT) paradox”, the productivity paradox, the Solow paradox, or a blend of these terms.

All abbreviations used in the dissertation are listed after the table of contents.

1.3. A note on productivity and other statistics

The dissertation refers to several sources of productivity statistics, which are based on an author’s own calculations, and which are in turn based on primary or official sources. The statistics are thus not always consistent and cannot strictly be compared. They do, however, reveal similar trends, which is the main point. As Cox and Alm (2003:6) states that “it’s a Herculean task to calculate a productivity number that sums up the efforts of 130 million workers, employed in millions of establishments that produce more than $11 trillion in output.”

Furthermore, the official statistics are revised periodically, and the base year is shifted forward, resulting in changes in the calculated levels and growth rates. The USA in particular revises its National Income an Product Accounts (NIPA) regularly. As the base year shifts, growth rates and other time series often differ, albeit sometimes only marginally. Therefore an author writing in the 1980s may have different set of numbers to work with compared to one writing 20 years later.

1.4. A note on productivity growth rates and productivity levels

Productivity growth rates must be distinguished from productivity levels. The debate around the productivity slowdown and productivity paradox in the US has centred largely on productivity growth rates, as US productivity levels are typically of the highest that has been attained globally. High productivity levels are the result of the accrual of high historical productivity growth rates. The productivity slowdown and productivity paradox are concerned with productivity growth rates, rather than with levels. A productivity slowdown does not mean that productivity levels are declining, but that the rate of increase is slowing. The study of productivity levels has been conducted by Maddison (1995 & 2001) and is of interest in analysing and comparing cross-country productivity performance.

1.5. The importance of productivity

Many economists have emphasised productivity's economic significance, for example, John Kendrick, in his path-breaking *Productivity trends in the United States* (Kendrick 1961:13): "The story of productivity, the ratio of output to input, is at the heart of man's efforts to raise himself from poverty."

The significance of productivity to developed and developing countries alike cannot be overestimated. All countries were once poor and underdeveloped and many economic historians are of the opinion that the developed countries have achieved economic growth and development largely through the dynamics of productivity. Whereas the history of economic growth and development reveals how the growth path towards economic advancement unfolds (as measured by a relatively high per capita GDP), the story of productivity is the main driving force through which the goal of sustainable and long-run economic advancement and progress is reached. Economic failures have often resulted from productivity failures.

One of the main objectives of economic development is the continual and cumulative improvement in the living standards of a country's citizens. The standard of living refers to the material well-being of an individual (or a household), based on the quantities of goods and services that are consumed. Productivity is the main cause of the improvement in living standards. Not only is productivity growth "the basic source of economic progress" (Gordon 1996:45), also “in the long run, productivity growth is the single most important economic indicator” (Paradox lost 2003:13).

Industry Canada (2003) has unpacked the relationship between the standard of living – as measured by per capita GDP – and productivity. The analysis shows that increases in the standard of living are caused by an increased amount of work being done, multiplied by increased productivity. These interrelationships are demonstrated by the following basic economic equation, reproduced here as an *aide-mémoire*:

$$\frac{\text{GDP}}{\text{Population}} = \frac{\text{Hours worked}}{\text{Workers}} \times \frac{\text{Workers}}{\text{Population}} \times \frac{\text{GDP}}{\text{Hours worked}}$$

The first term denotes increases in the standard of living (or per capita GDP); the second term and third terms denote the increased amount of work being done (people working longer hours and more people working); and the final term denotes increased labour productivity. Significantly, in the longer term, only increased productivity boosts the standard of living because “the prospects for growth in the other two factors will be exhausted” (Industry Canada 2003).

However, more fundamentally, differences in higher productivity growth rates affect the pace at which living standards improve. Applying the “rule of 73” and actual data (based on Cox & Alm 2003:8, exhibit 2), a productivity growth rate of 1.5% (1973 to 1995) implies living standards (as measured by per capita GDP) doubling every 48 years; whereas a productivity growth rate of 2.7% (1950-1973) implies living standards doubling every 27 years. But productivity growing at 3.2% (1995-2003) implies living standards doubling in a mere 22 years – in other words, in about a single generation.

According to Hall and Jones (1999:83), productivity also describes differences in efficiency between nations. Differences in output between countries can be interpreted as differences in human and physical capital as well as productivity. However, it is productivity that plays the key role. For example, based on extreme examples, in 1988, a US worker produced 35 times more output than a worker in Niger (Hall & Jones 1999:83): “Different capital intensities in the two countries contributed a factor of 1.5 to the income differences, while different levels of educational attainment contributed a factor of 3.1. The remaining difference – a factor of 7.7 – remains as the productivity residual.”

The full significance of this statement will become clear when growth accounting is discussed in chapter 2.

The importance of productivity needs to be emphasised because the subsequent discussion of the productivity slowdown and productivity paradox will appear trivial without an understanding of productivity's central role in economic growth and development, and in the improvement in national living standards and economic welfare.

Adam Smith (1982:443.) also discussed the importance of productivity in the *Wealth of nations*, first published in 1776:

> The annual produce of the land and labour of any nation can be increased in its value by no other means, but by increasing either the number of its productive labourers, or the productive powers of those labourers who had before been employed. … The productive powers of the same number of labourers cannot be increased, but in consequence either of some addition and improvement to those machines and instruments which facilitate and abridge labour; or of a more proper division and distribution of employment.

Historically, the debate about the significance of productivity to economic growth has been on-going since the late 1950s, with the publication of Solow's 1956 and 1957 articles, as well as those by Abramovitz (1956) and several studies by Kendrick (1961, 1984). Their research showed that (Metcalfe 1987:619):

> modern growth in the US economy was in proportionate terms at least three-quarters due to increased efficiency in the use of productive inputs and not to the growth in the quantity of resource inputs per se. The implication was quite devastating: the explanation of economic growth appeared to lie outside the traditional concerns of economists, to constitute a residual hypothesis.

In the late 1960s, Fabricant (1969:99) wrote that productivity is important for national earnings: "Two main causes determine the national average of hourly earnings. One is the general price level, and the other is national productivity." He argued that between 1889 and 1965 there was a close relationship between the rate of change of real earnings and in labour productivity, when average earnings multiplied by a factor of 20 (Fabricant 1969:99&103).

Another prominent economist, Paul Krugman (1994a:56) argued, more recently, in a memorable quote: “Depression, runaway inflation, or civil war can make a country poor, but only productivity growth can make it rich. In the long run, barring some catastrophe, the rate of growth of living standards in a country is almost exactly equal to the annual increase in the amount that an average worker can produce in an hour."

The theme of productivity was also taken up by the influential business writer and management guru, Michael Porter (1990:6), who wrote as follows in *The competitive advantage of nations*:

> We must abandon the whole notion of a "competitive nation" as a term having much meaning for economic prosperity. The principal economic goal of a nation is to produce a high and rising standard of living for its citizens. The ability to do so depends not on the amorphous notion of "competitiveness" but on the productivity with which a nation's resources (labour and capital) are employed. … The only meaningful concept of competitiveness at the national level is national productivity. A rising standard of living depends on the capacity of a nation's firms to achieve high levels of productivity and to increase productivity over time.

Another management guru, Peter Drucker, considers productivity from a different perspective. He links productivity growth to the determination of income distribution and income inequality in particular. Drucker argues that, according to Pareto's law, productivity determines income distribution and governments' redistribution efforts will be ineffective. Pareto's law states that national income is always distributed unequally; therefore the distribution of national income, that is, independently of its average level, is the same in all countries (Greenwald & Associates 1973:422). The reasons are as follows: "The less productive an economy, the greater the inequality of incomes. The more productive, the less the inequality" (Drucker 1989:67).

According to Rees (1980:1-2), productivity has several positive spin-offs. Firstly, it enables some people to consume more without causing other people to consume less; it may even result in all people consuming more. Income rises for all, rather than being redistributed. Secondly, following from the first proposition, productivity growth can mediate social conflict through the distribution of a "social dividend", because increasing income attenuates class conflict. Thirdly, falling productivity can add to inflationary pressures if there is "political and social bargaining over income shares" as some social groups attempt to keep their real incomes growing at rates consistent with the previously higher productivity growth (Rees 1980:2). Lastly, high productivity growth could help enhance social welfare, because the efficient use of factor inputs will produce high levels of measurable output of goods and services that consumers value, thus leaving some scope to produce more unmeasured outputs that improve goods and services of a "public good" nature and other social priorities, such as improved health, safety, conservation and the environment.

Productivity also helped to reduce the average working week in the USA from "76 hours in 1830 to 60 in 1890, 39 in 1950 and just 34 today" (Cox & Elm 2003:5), thus substantially adding to the availability of leisure time.

Productivity and the accompanying improvement in living standards and welfare are achieved gradually and in the long run. However, the powerful and compounding effect of small but increasing rates of change is a commonplace in economics. To illustrate from historical productivity data: according to Fabricant (1969:13 & 20), during the 80-year period from 1889 to

1969, labour productivity growth averaged 2.4% in the private domestic economy, which excludes the government sector (labour productivity falls to 2.1% for the whole economy if the government sector is included); whereas total factor productivity equals 1.7% over the same period. These figures are considered to be "sharp – even remarkable" when their compounding effect is considered, since they imply that in 1969 the "average worker in the United States today produces more than six times as much in an hour of work as did his grandfather or great-grandfather in 1889" (Fabricant 1969:14).

Indeed, the long run, despite being famously dismissed by Keynes with the quip that in the long run we are all dead, is the appropriate time frame of reference for productivity changes. Jacob Viner (1940:112) stressed the importance of the long run: "No matter how refined and how elaborate the analysis, if it rests solely on the short view it will still be close to the layman's economics and still be a structure built on shifting sands."

William Baumol echoes this view (Baumol 1989; Baumol, Blackman & Wolf 1989, chapter 1), and argues that "productivity growth can provide miracles in the long run and already has yielded improvements in living standards unimaginable at any time in human history before the 19th century" (Baumol 1989:611).

In sum, productivity is more evolutionary than revolutionary, an expression attributed to the Federal Reserve Chairman, Alan Greenspan (Roach 1998a:156).

In terms of growth analysis, through comparative cross-country studies, with particular reference to developing countries, TFP plays an equally important role. It is opposed to the “capital fundamentalism” hypothesis, a term introduced by King and Levine (1994), which states that capital and investment are the main drivers of long-run economic growth (Easterly & Levine 2001: 179):

> Factor accumulation does not account for the bulk of cross-country differences in the level or growth rate of GDP per capital (*sic*); something else – TFP – accounts for a substantial amount of cross-country differences. Thus, in searching for the secrets of long-run economic growth, a high priority should be placed on rigorously defining the term “TFP,” empirically dissecting TFP, and on identifying the policies and institutions most conducive to TFP growth.

The topic of productivity, critical as it is, however, is not the subject of this dissertation. A comprehensive and perceptive discussion of the importance of productivity can be found in *Productivity and American leadership: the long view*, by William Baumol, Sue Blackman and Edward Wolff (Baumol et al. 1989:9-94, chapters 1-3) and in many other publications (see the bibliography).

It is difficult to overstate the significance of productivity. In a nutshell, it is regarded by many economists, government agencies and businessmen alike as a – if not *the* – *sine qua non* of economic growth and development.

1.6. The 1973 productivity growth slowdown

In the early 1970s, in the USA, the post-war productivity growth machine came to a sudden halt, when productivity growth suddenly halved. The productivity numbers speak for themselves: according the US Bureau of Labor Statistics (BLS), between 1948 and 1973, the average growth rate in labour productivity (output per hour of all persons) was 2.9% per annum; however, between 1973 and 1979 it fell to 1.2%; between 1979 and 1990 recovered to 1.4%, and between 1990 and 1995 it rose marginally to 1.6% per annum in the private nonfarm business (BLS News 2003:6, table B).

It is not surprising that when the USA experienced a productivity slowdown, the news was received with alarm. The country experienced a recession in 1974-1975 with rising unemployment and inflation, largely because of the oil crisis, when the crude oil price suddenly rose steeply. Labour productivity was seen as the culprit and workers were accused of not producing enough output per man-hour (Sweezy & Magdoff 1979). Productivity henceforth occupied centre stage in the economic debate in the 1970s, during the Carter administration.

Several economists expressed their concern. For example, Denison (1979b:1) argued as follows "Beginning in 1974 the situation became disturbing and also puzzling." Darby (1984:301) refers to the productivity slowdown in terms of a "productivity panic", demonstrating the seriousness of the issue: "Indeed something akin to a panic has followed reports that labour productivity growth declined from an average annual rate of 2.6 percent over 1948-65 to 1.9 percent over 1965-73, and to 0.5 percent from 1973 to 1979."

In a similar vein, Baumol (1989:611) stated the following:

> A near flood of writings tell the American public that the United States teeters on the brink of economic mediocrity, its competitive position about to be lost to Japan, to the other miracle economies of the Far East, and even to the venerable industrial economies of Europe. Declining U.S. productivity growth coupled with the distinctly higher growth rates of its rivals, both of which are very real, are generally cited as the prime reasons for his prospect.

The concern was that the USA would lose its economic hegemony and experience a reversal in living standards, the advance of which was painstakingly achieved over a century (Baumol et al. 1989:29-64, chapter 3).

According to Arnold and Dennis (1999:10), the slowdown between 1973 and 1989, however, if placed in a broader historical perspective "looks less like an aberration and more like a return to longer-term rates of growth." **Table 1.1** shows that the 1973-1989 slowdown merely reverted to previous long-term rates of per capita GDP growth. Similar trends are discernible in the average growth rate of 14 European capitalist countries, including the USA and Canada. The latter variable is a more appropriate measure for historical comparisons and is more readily available. These figures reinforce the relevance of taking a long view. Gordon (1999b:124, table 1) draws a similar conclusion.

Table 1.1: Per capita GDP growth (%)

	1820-1870	1870-1913	1913-1950	1950-1973	1973-1989
US	1.2	1.8	1.6	2.2	1.6

Source: Arnold & Dennis (1999:10) (based on Maddison)

The causes of the abrupt slackening in productivity growth in the 1970s were the subject of analysis before it was labelled the productivity paradox (Denison 1979b; Maddison 1987). USA economists debated the slowdown with intensity. For example, in June 1980 the Federal Reserve Bank of Boston held a conference entitled "The Decline in Productivity Growth", where 13 prominent economists debated the issue. Also, in 1988, a conference, entitled "Symposium on the Slowdown in Productivity Growth", was held on the productivity slowdown and the findings published in *The Journal of Economic Perspectives* in 1988, with contributions by eminent economists such as Michael Boskin, Stanley Fisher, Zvi Griliches, Dale Jorgenson and Mancur Olson. There are many other comprehensive studies of the slowdown that appeared soon after it first became apparent in the 1970s, including Baumol and McLennan (1985), Baily and Gordon (1988), Denison (1979a; 1979b & 1983) and Nordhaus (1972).

The productivity growth slowdown was therefore a precursor to the productivity paradox. Prior to 1973, there were short periods of declines in productivity growth rates, but the causes of the slowdown could generally be explained. It was only after 1973 that the causes of the productivity growth slowdown could not be easily accounted for (Denison 1979a: 122). In short, there appeared to be a structural break in mid-1973 (Blinder 2000).

1.7. Solow and the productivity paradox

The debate around the productivity slowdown made a *volte-face* after a now-famous quip and frequently quoted remark by Robert Solow, that the computer age is evident everywhere except in the productivity statistics (Solow 1987:36). In a review of a book by Cohen and Zysman (1987), which deals with the myth of de-industrialisation of the American economy, captioned *We'd better watch out* (Solow 1987:36), Solow quotes the authors' view on technology and productivity: " 'We do not need to show that the new technologies produce a break with past patterns of productivity growth. …[That] would depend not just on the possibilities the technology represents, but rather on how effectively they are used.' "

Solow then continues, expressing the essence of his view of the authors of the book's position and, more importantly, of the computer revolution in general: "they, like everyone else, are somewhat embarrassed by the fact that what everyone feels to have been a technological revolution, a drastic change in our productive lives, has been accompanied everywhere, including Japan, by a slowing down of productivity growth, not by a step up. *You can see the computer age everywhere but in the productivity statistics* (italics added)."

This quote sums up the core of the productivity paradox: a technological revolution based on computerisation was accompanied by a slowing down of productivity growth. This unexpected outcome – the productivity paradox – was aptly described by Brynjolfsson and Yang (1996:2) as a clash of expectations and statistics.

Solow's quip has given rise to a lively debate about productivity, economic growth and policy issues in the USA. His aphorism suggests a causal link between increasing computerisation and the general productivity slowdown. It is evident from the above quote that Solow had two things in mind. Firstly, high investment in ICT was accompanied by slow productivity growth, and computerisation was identified as the culprit. Secondly, Solow had not only the slowdown in the USA in mind, but also the international implications and consequences of the productivity slowdown, which is evident in his reference to Japan. Indeed, subsequent research claimed that the slowdown was not caused by factors unique to the USA (Motley 1993).

The debate extended to the co-called "new economy", which the productivity paradox appears to undermine. According to Whalen (2001:42), "If the New Economy can be summed up in one word, it would be "productivity"." Advocates of the new economy believed that an era of sustained and permanent productivity gains was just round the corner, in which new advances in technology, particularly computer technology, will play a fundamental role. The new economy has indeed been acclaimed as the Third Industrial Revolution. New economy advocates claim that technological innovation and globalisation will raise productivity growth (Greenspan 1998). Jorgenson and Stiroh (1999:110) refers to the optimism based on the expected spillovers generated by the IT investment into the rest of the economy as "a kind of a Computer Cargo

Cult". This view is summed up by Jorgenson and Stiroh (2000:186): “that the impact of IT is like phlogiston, an invisible substance that spills over into every kind of economic activity and reveals its presence by increases in industry-level productivity growth across the U.S. economy”.

In the USA, and elsewhere, the new economy is purported to herald a "profound and fundamental alteration in the way our economy works" which "creates discontinuity from the past and promises a significantly higher path of growth than we have experienced in recent decades" (Greenspan 1998). Based on high productivity growth, the new economy is purported to have rewritten the “rules of the game” and the economy can grow at a faster pace than was previously possible, without generating higher inflation (Krugman 1997a:124). In other words, the new economy can permanently “raise the speed limit” of the economy in terms of growth (Jorgenson & Stiroh 2000b). Whereas the consensus view was that the US economy’s potential growth was about 2.2% previously, the new economy optimists believed that GDP growth rates of 3.5% or even 4% were achievable (Jorgenson & Stiroh 2000b:229). Thus the new economy is perceived to alter the organisation of production, international trade and the delivery of value to customers.

The ultimate embodiment of the new economy is of course in the internet, or the so-called “Information Superhighway” (Sichel 1997a:2). Numerous publications have dealt with the burgeoning internet and will not be re-examined here. The internet’s size as measured by its contribution to GDP is still relatively small. In 1998 it contributed some US$159 billion or 1.8% to GDP and e-commerce sales were estimated at 1.01% of retail sales (Landefeld & Fraumeni 2001:26). However, it is worth remembering just how optimist the electronic commerce enthusiasts were. In a 1999 survey of business and the internet by the influential newspaper, *The Economist*, the opening paragraph states: “In five years’ time … all companies will be Internet companies, or they won’t be companies at all” (Net imperative…1999:5).

The new economy adherents also base their enthusiasm on the idea that the golden age of the computer will take time to assert itself, as was the impact of the electric motor on manufacturing in the 1920s (Gordon 1999a:2). This view is based on the influential paper by Paul David "The dynamo and the computer: an historical perspective on the modern productivity paradox" (1990). The computer is a general purpose technology, whose impact diffuses only slowly and gradually through the economy.

Although the decline in productivity growth has been referred to as "the major macroeconomic event in the United States over the past generation" (DeLong 1997:2), as can be expected not everyone was panic-stricken by the productivity paradox, certainly not members of the ICT industry! It appears that the concern was mostly confined to the economics profession. One ICT industry commentator, Ives (1994:xxi), the editor of the influential *MIS Quarterly*, argued that most of the arguments in support of the “alleged paradox” are largely unfounded.

Solow's sceptical comment was particularly pertinent, because his two seminal papers "A contribution to the theory of economic growth" (1956) and "Technical change and the aggregate production function" (1957) established him as a leading expert in the subjects of economic growth and technical change. Confusingly, these two papers draw opposite conclusions; the 1956 paper developed the Solow growth model, while the 1957 paper argued that it was productivity that mattered, not capital accumulation (Bosworth & Collins 2003:190). In his 1957 paper, Solow came to the startling conclusion that capital formation played a smaller role in economic growth than had hitherto been expected. That study thus contradicts the "capital fundamentalism" view (see King & Levine 1994), the dominant economic development theory in the neoclassical paradigm in the 1950s and 1960s, and which asserted that investment and capital formation are the primary determinants of long-run economic growth (Easterly & Levine 2001:260).

Solow (1957:320) showed, in particular, that whereas gross output per hour doubled from 1909 to 1949, 87.5% of the increase was attributable to technical change and the rest to the use of capital. It examined productivity from the supply side (Syrquin 1988:254). Thus Solow's research results attributed seven-eighths of the increase in output to "technical change in the broadest sense" (Solow 1988a:313). According to Metcalfe (1987:619): "The implication was quite devastating: the explanation of economic growth appeared to lie outside the traditional concerns of economists, to constitute a residual hypothesis."

Solow (1957) used the production function to underpin the analysis of economic activity and analysed the role of capital in labour productivity trends. The rate at which the production function shifts outwards is referred to as total or multifactor productivity, which is also a "residual". Generally, MFP is a measure of technical change. The fact that MFP is a residual indicates that it also manifests other influences (Dean & Harper 1998:7). The full result that Solow obtained was that "the rate of growth of labour productivity depends on the growth rate of the capital-labour ratio, weighed by capital's share, and the growth rate of MFP" (Dean & Harper 1998:7). Solow argued that MFP, rather than labour productivity, was a superior measure of technical progress (Dean & Harper 1998:7).

Generally, Solow's work initiated a new research programme, growth accounting, based on the aggregate production function. Solow's 1957 paper is also the methodological basis of the BLS's productivity measurement program (Dean & Harper 1998:7).

His conclusions were also in broad agreement with other economists about the role of technology in economic growth, particularly Denison (1967, 1974, 1979a, 1987). Solow (1988a:314) concurred with Denison that "technology remains the dominant engine of growth, with human capital investment in second place". Yet "in a certain subtle sense" labour is the most important factor of production, as evidenced by the fact that wages account for some three-fourths of national product (Samuelson 1980:502).

Solow received the Nobel Prize in Economic Science in December 1987 "for his contributions to the theory of economic growth" (Nobel Prize 1987). In his Nobel Lecture, Solow (1988a) provided valuable insights into the productivity paradox. His model concluded that permanent increases in savings and investment will lead to a higher *level* of real income, but not to a higher *growth rate* of real income; only technical progress, in the broadest sense, will result in a higher *growth rate* in real income. A short-run growth spurt may result from higher savings and investment, but not a permanently higher growth rate – the permanent growth rate is independent of the saving and investment rate. Technological development is therefore the main engine of growth in the long run (Solow 1988a:314).

1.8. The productivity paradox and computerisation

The economics of computerisation plays a vital part in the productivity paradox literature. In *The computer revolution: an economic perspective*, Sichel (1997a) examines computerisation and the productivity paradox from an economic perspective, a book which Solow (1998) favourably reviewed in *Challenge*. Oliner and Sichel (2000) and Loveman (1994) also examine the role of IT in productivity.

The first computer was delivered to a commercial customer in 1954 (Baumol 1989:321). Computers become economically important from about 1959 – when revisions to the System of National Accounts (SNA) to account for quality changes in computers and peripherals were first introduced in December 1985, indexes were estimated back to this date (Landefeld & Grimm 2000:18). The personal computer (PC) boom followed in 1983 and 1984, when businesses spent hundreds of billions of dollars on purchasing office computers (Bowen 1986:20-21). Bowen's 1986 article, published in the influential *Fortune* magazine, was entitled "The puny payoff from office computers".

Significantly, the quality-adjusted prices of computers and peripheral equipment have declined at surprisingly high rates, at an average of about 24% per annum in recent years, according to a recent estimate (Landefeld & Grimm 2000:18). According to Sichel (1997a:3), between 1970 and 1994, prices of computers and peripheral equipment declined at an average annual rate of 15.1%, but over the same period the overall price level increased by 5.2%. According to the Economic Report of the President (US Congress 2003:68), computer prices fell at a 26% annual rate between 1995 and 2000. These prices are not the actual prices paid for computers and equipment in shopping outlets, but market prices adjusted for quality changes. The computing powers of mainframe computers, minicomputers and personal computers (including peripheral equipment) have all risen at an equally rapid pace and this is the main reason for the decline in computer prices.

It is reasonable to say that IT and computerisation are therefore possible candidates for the slowdown in productivity growth, because the personal computer was invented and computerisation became more widespread in the 1970s, when investment in and use of IT increased dramatically. It therefore seems that there is some association (whether causality or correlation) between IT investment spending and lower productivity. This counter-intuitive result – that, in effect, computers slow us down – is more plausible when we consider that ICT costs can be high and reduce the needed flexibility to improve productivity. For example, Stephen Roach (1998a:158) points out the enormous costs associated with the Year 2000 bug or Y2K were "a prime example of the deadweight of the information age".

However, the main issue whether or not the association between computerisation and productivity is causal or merely coincidental remains undecided. The aim of this dissertation is to examine this issue more closely.

1.9. The 1995 productivity growth recovery and Solow's ostensible retraction

After 1995 there was a sudden productivity growth acceleration. According to the BLS (BLS News 2003:6, table B), labour productivity between 1995 and 2000 bounced back to 2.5% per annum in the private nonfarm business. *The Economist* newspaper declared that the '"productivity paradox" has been solved' (Paradox lost 2003:13). Advocates of the new economy have not been disappointed, as higher productivity growth is a cornerstone of the "new economy" paradigm.

In 2000, Solow is reported to have said: "You can now see computers in the productivity statistics", but added that "I will feel better about the endurance of the productivity improvement after it survives its first recession" (Uchitelle 2000:4). Subsequently, in 2002, Solow stated the following in an interview (Clement 2002): "It could mean that eventually productivity responded, that at last we do see computers in the productivity statistics.… Even now, however, we don't have the complete story. … there does not appear to be a miracle in productivity terms that we can attribute to the computer. … So I think that the outcome is still unresolved."

Solow's partial retraction has not been as widely reported as his earlier famous pronouncement, but both his change of opinion and reservation are important.

The productivity recovery, however, deepens the paradox instead of resolving it. This dissertation will deal mainly with the period from 1948 to 1995 and will refer to but not examine in depth the recovery period of 1995 to 2002. There are several reasons for this decision.

(1) Productivity statistics are revised and there is a delay before the results are released. Labour productivity statistics are available on a quarterly basis, but MFP statistics are only published after a long delay. At the end of 2003, the labour productivity statistics for 2003 were published, but MFP statistics for 2001 were only published in April 2003.

(2) Productivity growth trends and the business cycle are positively correlated. It is a stylised fact that both labour productivity and multifactor productivity are procyclical – thus productivity rises in booms and falls in recessions (Fernald & Basu 1999:1). Output growth and productivity has a correlation coefficient of about 0.8 (Fernald & Basu 1999:3). According to Arnold and Dennis (1999:8), labour productivity growth is weaker or negative during economic contractions, but recovers during an economic expansion. According to the standard view, productivity is procyclical because: ”Labor productivity falls when output falls because firms retain more workers than required to produce low current output. They do this to avoid the costs of laying workers off now and hiring replacements in the future when activity recovers” (DeLong & Waldman 1997:33).

This implies that the business cycle must be correctly assessed and have run its course before an accurate assessment can be made. Unless a business cycle has been completed, a transitory productivity revival could be confused with a permanent one (Gordon 2000b:54). According to the National Bureau of Economic Research (NBER), the economic research institution that determines the USA business cycles, the most recent trough (at the time of writing) occurred in March 1991 and peak in March 2001, a record expansion of 120 months or 10 years.

(3) Productivity must be studied over the long term, because it influences the economy persistently and cumulatively, albeit gradually. Examining short-run fluctuations can be misleading as the long run is the appropriate time frame for productivity analysis, as was argued above. The recovery period from 1995 to the present is relatively short in comparison with the earlier productivity cycles.

Stephen Roach, a long-standing and guarded IT sceptic, wrote that productivity must be distinguished from efficiency. In the mid-1990s, downsizing and other forms of cost-cutting were widely used to improve profitability, thus reducing labour and capital resources and improving efficiency. Although this can produce the same macroeconomic results as a true productivity recovery (Roach 1998a:154), it will not result in sustained productivity improvements, but only short-term gains. Furthermore, “If a new era of prosperity is truly at hand, there must be more than slash-and-burn cost cutting and micro miracles. The micro must be converted to the macro” (Roach 1998a:160). Only continual investment in innovation and human capital can lead to sustained productivity improvements.

Moreover, during periods of accelerating productivity growth, there has been an increase in employment (Roach 1996:82): “Sustained productivity growth, however, hinges on getting more out of more — deriving increased leverage from an economy’s (or company’s) expanding resource base”.

(4) The productivity growth resurgence in 1995 presents additional problems, which do not relate directly to the productivity paradox. Despite similarities, the recent sustained resurgence requires a separate study. The productivity growth slowdown period is marked by structural breaks in 1973

and 1995 in the productivity growth rates when compared to previous trends. One of the new economy sceptics, Robert Gordon (2003), points out that the revival actually presents five *new* puzzles, and has changed his mind to become a new economy devotee. It would, however, be as difficult to show that computerisation is responsible for the productivity growth revival, as it is to show that it caused the productivity growth slowdown.

The recovery has indeed been remarkable: according to *The Economist* (The new "new economy" 2003:65), labour productivity growth recovered to 2.5% from 1995 to 2000; and at an even higher rate of 3.4% from 2000 to 2003. According to the 2003 Federal Reserve Bank of Dallas Annual Report (Cox & Alm 2003:8, exhibit 2), the productivity resurgence "has not only reversed the 22-year slowdown but also eclipsed the historical trend of 2.3 percent a year" as shown by the following trends (**Table 1.2**):

Table 1.2: Productivity growth trends: 1870 to 2003

Period	**Change**
1870-2003	2.3%
1950-1973	2.7%
1973-1995	1.5%
1995-2003	3.2%

Source: Cox & Alm (2003:8, exhibit 2)

Finally, as two eminent economists observed, the attention has shifted somewhat in recent years: "The post-1973 puzzle was never resolved, just abandoned by economists when they were confronted with a new problem – the acceleration of U.S. productivity after about 1995" (Bosworth & Triplett 2003:1). However, the productivity growth slowdown remains a challenge to explain and understand, because it goes to the heart of many key economic issues, as argued above.

1.10. Concluding remarks

The USA is one of the most computerised economies in the world. More than half of all homes have personal computers, many with high-speed access to the internet. Business investment in IT resulted in the computer industry becoming a growth industry in the closing decades of the 20th century. Billions of dollars have been and continue to be spent on ICT investments. Roach

(1991:84) refers to this phenomenon as a “technology overdose” because corporate America has taken an extremely large wager on the productivity pay-offs of computerisation. The enormous fixed costs associated with ICT investments have led the US economy to move from a variable-cost to a fixed-cost regime, particularly in the service sector.

It is almost impossible to conceive of the US economy outside the context of the impact of computers. The productivity paradox has played a key part in the assessment of the impact of computerisation and ICT not only on the standard of living and economic growth in the USA and other OECD countries, but also in some developing countries.

The USA has largely escaped from poverty by means of productivity growth. It has the highest labour productivity levels and per capita GDP in the world today. According to Maddison (2001:351), in 1998 the USA had the highest labour productivity level (GDP per hour worked) in the world of $34.55 (measured in 1990 international dollars per hour). In comparison, the UK’s productivity was $27.45 and Japan's $22.54. Furthermore, in the same year the USA had a per capita GDP of $27 331 (measured in 1990 international dollars), compared to the Western European average of $17 921 and the world average of $5 709 (Maddison 2001:28 & 279). There is no greater testimony than these figures to the power of human beings’ productive efforts to raise themselves from poverty.

2. CHAPTER 2: PRODUCTIVITY AND TECHNICAL CHANGE

2.1. Overview

Chapter 1 reviewed the economic importance of productivity growth. Chapters 2 and 3 will analyse the building blocks of productivity analysis, including production functions, technical change and the measurement of productivity using index numbers. The analytical literature on the Solow computer paradox refers frequently to these topics. Thus, an understanding of the computer paradox is difficult, if not impossible, without an understanding of these concepts. Moreover, a knowledge of the methodology of the growth accounting approach is useful in the critical analysis of productivity and the computer paradox. Also, the statistical agencies in the US (such as the Bureau of Labor Statistics [BLS], Bureau of Economic Analysis [BEA], etc.), as well as those of other countries, rely specifically on these concepts and methodology to construct their national accounts.

Chapter 4 will explain how productivity and computers are accounted for in the US national accounts while chapter 5 examines the economics of computerisation.

This chapter analyses the relationship between productivity, the methodology of the neoclassical research programme, technical change, the total factor or multifactor productivity "residual" (also called the Solow residual), and the Cobb-Douglas production function. These topics are all part of what is called growth accounting. They form an organic whole and are the building blocks of productivity measurement in the national accounts. Schreyer and Pilat (2001:131) argue that Solow's aggregate production function approach to technical change and productivity analysis (see Solow 1957) has yielded fruitful results, and that "the theory of the firm, index number theory and national accounts" are thus consistently integrated in the System of National Accounts (SNA).

2.2. Productivity measurement in the neoclassical framework

In terms of economic models, the neoclassical view and the new growth theory are incorporated in productivity measurement. In the neoclassical view, capital accumulation drives growth in the short run, but because capital is subject to diminishing returns, in the long run, productivity is largely driven by exogenous (i.e. largely unexplained) technical change. The so-called "new growth theory" goes beyond this view and avoids diminishing returns to capital and argues that technical change is endogenous. This line of research was pioneered by Romer and is known as endogenous growth theory (Romer 1990b). Neoclassical analysis can explain *what* happened to growth in the USA (for example, after 1995 it was mainly ICT investment); whereas only the new growth theory can explain *why* technical progress accelerated in ICT industries (after 1995) (Stiroh 2001a:37-38). Thus both models can add to the understanding of productivity growth.

According to Prescott (1997:10-11), the neoclassical production function is the cornerstone of the theory of multifactor productivity and adds: "A beauty of this simple construct is that it accounts for the balanced growth that has characterized the U.S. economy for nearly two centuries. Another beauty of this construct is that it deals with well-defined aggregate inputs and outputs. A final beauty is that it is based upon a lot of theory."

Several characteristics of growth accounting and the neoclassical framework are discussed below.

Firstly, long-run growth is driven by technical change only (Stiroh 2001a:40). Capital accumulation drives growth only in the short run (Stiroh 2001a:37). Technical change is exogenous and is not explained in the model; hence, the very foundation of economic growth is largely unexplained (Stiroh 2001a:37). Technical change is equivalent to or shorthand for total factor productivity. In the neoclassical framework, if capital accumulation instead of TFP is the dominant factor or source of growth, it is expected that growth will eventually slow down in the long run. This issue is fundamental to the neoclassical view: growth studies that find capital accumulation to be more important than TFP do not disprove the neoclassical model. They merely imply that growth will eventually slow down, because of diminishing returns to capital, as only TFP supports long-run growth. Thus an excessive reliance on capital accumulation and capital formation can only result in slower economic growth (Collins & Bosworth 1996:187). The study by King and Levine, *Capital fundamentalism, economic development, and economic growth* (1994: 282) concluded that capital accumulation is part of economic development, but does not ignite growth: economic growth results in capital accumulation, not the other way round. The arrow of causality runs from growth to capital accumulation. Capital fundamentalism is embodied in the well-known Harrod-Domar (H-D) growth model, which can be summed up as the view that "increasing investment is the best way to raise future output" (King & Levine 1994:259).

This debate has focused in particular on economic growth in East Asia or the so-called "Asian tigers", that is, Singapore, Hong Kong, South Korea and Taiwan. According to Collins and Bosworth (1996:141), with reference to the East Asian countries: "We suggest that there is some evidence that these economies are evolving toward a greater emphasis on TFP gains and that future growth can be sustained." This is linked to the debate sparked by the 1994 article by Paul Krugman (1994b), *The myth of Asia's miracle*, which is based on Young's 1995 article, *The tyranny of numbers: confronting the statistical realities of the East Asian growth experience*. Krugman argued that economic growth based merely on increases in input (as in the former Soviet Union and East Asia) without an increase in productivity, that is, in the efficiency – or growth in output per unit of input – with which the inputs are used, will result in diminishing returns (Krugman 1994b:172). Rapid growth rates in the former Soviet Union and the Asian Tigers can easily be explained as primarily input-driven growth, without any growth in efficiency. This also throws light on the productivity panic after the 1973 productivity slowdown in the USA, because long-term growth is associated more with productivity growth rather than simply input-driven growth and capital accumulation.

Secondly, broadly defined capital investment produces largely internal benefits (which accrue only or mainly to the investor, with no benefits spilling over to the boarder economy) and decreasing or diminishing returns to scale (Stiroh 2001a:38 & 42). However, the new growth theory typically stresses external benefits and constant as well as increasing returns to scale.

Thirdly, in terms of the direction of causality "faster technical change induces higher output, saving, investment, and capital accumulation, so part of historical capital accumulation itself is due to technical change in a deeper sense" (Stiroh 2001a:40).

Generally, capital accumulation is a necessary but not a sufficient condition for growth (Solow 1962:86). Growth accounting captures all the phenomena that affect economic growth, thus accounting for the sources of growth by breaking down GDP growth into factor inputs and production technologies (Barro & Sala-i-Martin 2004:433).

2.3. Growth accounting and the aggregate production function

According to Barro and Sala-i-Martin (2004:433), growth accounting was pioneered by Solow (1957), Kendrick (1961), Denison (1962) and Jorgenson and Griliches (1967). Growth accounting is an empirical methodology which separates GDP growth into changes associated with the factor inputs and production technologies (Barro & Sala-i-Martin 2004:433).

Growth accounting has become the foremost heuristic device for gaining an understanding of how economies grow and develop and how development in different economies can be compared in this regard. Growth accounting encompasses all the economic tools discussed below, including the Cobb-Douglas production function, the Solow residual and index numbers.

Growth accounting undoubtedly has some limitations. It separates the overall growth rate into the *proximate* sources of growth, such as labour, capital and technology. These are the customary exogenous variables used in economic models (North 1993:65). However, the *ultimate* elements or variables underlying economic growth are not explained, because growth accounting cannot identify the primary causes of growth (North 1993; Collins & Bosworth 1996:139). In a similar vein, Barro and Sala-i-Martin (2004:457) state that growth accounting "is only an accounting decomposition" and that it does not amount to a theory of growth (2004:460). According to these authors, the ultimate causes of growth are institutions, government policies, consumer preferences, technology, and other factors.

The neoclassical production function is the foundation of the neoclassical growth theory. The Cobb-Douglas production function has been the preferred form of this function in most neoclassical research in this area. In a review of production functions, Griliches and Mairesse (1995:2) argue that the production function "is a tool, a framework for answering other questions". The empirical estimation of the production function presents many statistical difficulties. For example, the estimation of the production function by means of ordinary least squares (OLS) requires the explanatory variables to be exogenous. This requirement is unlikely to hold given the available data – hence the usual identification problem arises. The identification problem arises when simultaneous equations (such as supply and demand using price and quantity data) are estimated in econometric models (see Koop 2000:207).

The Cobb-Douglas function is but one of many functional forms that aggregate production functions can assume. This function is one specific form of the more general constant elasticity of substitution (CES) function and translog production function. According to Maddala (1979:310): "Different functional forms for the production function imply different schemes for weighing the input ratios in the construction of the input index." The weighting issue is discussed below.

Many economists have pointed out the problems arising from aggregation. One problem is how to derive predictable macroeconomic variables from the underlying microeconomic variables. For this reason, 19th century neoclassical economists refused to aggregate micro-production functions into an aggregate level (Blaug 1992:171).

The aggregate production function was attacked by the Cambridge School of Economics (CSE) in England. The controversy became known as the Cambridge Controversy, which raged in the 1930s between the CSE and the Massachusetts Institute of Technology (MIT) at Cambridge in the USA. This controversy and problem of aggregation is reviewed in chapter 6 because it pertains to the critique of productivity analysis.

The aggregate production function can be used to analyse capital-labour substitution and increased efficiency in the use of resources. According to Metcalfe (1987:619), the early studies were based on the aggregate production function as the central organising concept. Growth in output per worker was disaggregated into: (1) capital-labour substitution, demonstrated by a movement along the production function; and (2) increased efficiency in resource use, demonstrated by shifts in the production function.

However, Nelson (1973) asks whether growth accounting leads to a new understanding or to a dead end, and argues that it may be theoretically impossible to distinguish between movements along a production function and shifts in the production function. This issue is explored further below under forms of technical change.

2.4. Primal and dual approaches to productivity measurement

The standard method of measuring TFP is also referred to as the primal method, which uses physical stocks of inputs. Solow employed this method to estimate productivity growth and technical progress in his 1957 paper. In contrast, the "dual" method uses factor price data rather than information on stocks (Aiyar & Dalgaard 2005:83). The dual method was pioneered by Jorgenson and Griliches in their seminal paper, *The explanation of productivity change* (1967). They showed the equivalence between price- and quantity-based growth accounting methods (Jorgenson & Griliches 1967:252).

Several studies used the two different approaches to examine the East Asian growth miracle (Hsieh 1999, 2002; Young 1995). Some studies, that rely on the primal approach (e.g. Young 1995), found that factor accumulation was the driving force and that TFP played almost no role in East Asia's impressive growth performance. This view was challenged by Hsieh (1999, 2002), who refined the TFP calculations by employing the dual approach. He found that TFP did in fact play the most important part in East Asia's high growth performance. The dual approach will be discussed in more detail in chapter 6.

2.5. The production function and productivity

Production functions generally define the technological relationship between average input levels and the level of output. The inputs can be any combination of the usual factors of production, land, labour, capital and entrepreneurship.

The general production function is of the form

$$Q = f(K, L)$$

where Q = output of the whole economy; K = total quantity of capital; and L = total quantity of labour. When the production function shifts over time, it can be written as

$$Q = f(K, L, t)$$

where t = technical progress. The variable t is introduced specifically to allow the production function to shift over time (Allen 1973:236). The equation can be extended to include other inputs, such as intermediate inputs and raw materials. This is discussed further in chapter 5.

2.6. The basic growth accounting formula

Under neutral technical change (discussed below) the production function is written as:

$$Q = A\,f(K, L)$$

where Q = output; A = the efficiency parameter or technical progress; K = capital; and L = labour. It can be shown that the growth rate of output will be

$$\frac{\Delta Q}{Q} = \frac{\Delta A}{A} + \alpha \frac{\Delta K}{K} + \beta \frac{\Delta L}{L}.$$

This is the basic growth accounting formula (Hall & Taylor 1997:75-77 & 96-97). The parameter α denotes the share of capital in national income; and the parameter β the share of labour in national income. These are calculated or estimated empirically (Barro & Sala-i-Martin 2004:434). The values of α and β are derived from the national income and product accounts (NIPAs). Typical values are α = 0.3 and β = 0.7 (Hall & Taylor 1997:97). This issue is reviewed below. Chapter 4 will show how actual values of the shares of capital and labour in income are derived from the NIPAs.

The value of $\frac{\Delta A}{A}$ is a residual value because it is not calculated directly. This became known as the Solow residual and is equated with productivity and technological change. The residual will be discussed in more detail in chapter 5.

2.7. Measurement of output and input

The measurement of output and input is complex and will be briefly reviewed in relation to the central question of the productivity paradox. Both output and input are measured in terms of market transactions (Jorgenson & Griliches 1967:251). Economic activities that are nonmarket based are therefore excluded from growth accounting. There must be a match between goods and services produced and the inputs used to produce the output, because a mismatch will distort the measurement of productivity (NRC 1979:88-90). For example, leisure and charitable activities are excluded, because they are not market transactions (NRC 1979:89).

Output at national level is measured by the real product or output (in other words, real GDP) in the familiar system of national accounts.

The two main factor inputs are labour and capital. It is imperative that capital and labour inputs should be measured accurately. Capital input can be measured by the flow of services from the stock of physical capital, such as the amount of “machine-hours” (Barro & Sala-i-Martin 2004:436-438). Similarly, labour input can be measured by the number of workers or, more accurately, the number of hours worked. Inputs can be adjusted for quality changes (Barro & Sala-i-Martin 2004:436-438).

When labour and capital inputs are adjusted for quality changes, the size of the residual is reduced, as shown by Jorgenson and Griliches (1967). Therefore a failure to adjust inputs for quality improvements will overstate productivity growth and hence technological progress.

Since computerisation is a form of capital, it is necessary for it to be measured accurately. There are several major concerns in the measurement of computers (particularly accounting for quality improvements), which forms the core of the criticisms of the computer productivity paradox. These concerns will be discussed in chapter 3 as well as in other sections of this dissertation. Many of these issues have been used as a basis for criticising the growth accounting methodology, and will be taken up in chapter 6.

2.8. The Cobb-Douglas production function and productivity

The Cobb-Douglas production function occupies a controversial role in economic analysis, despite the fact that it is ubiquitous. Its widespread use derives from the ease with which it can be developed mathematically (Brown 1987:460). Brown (1987:460) captures its contentious nature, in stating that "it possess restrictive properties and perhaps for that reason it has become for some an object of disdain, often regarded as a child's toy in the world of real economics. But for others, the Cobb-Douglas is at least a venerable form, and, effectively it and its putative inventor are regarded fondly."

The various criticisms of the Cobb-Douglas production function will be discussed in chapter 6, where several explanations of the productivity paradox will be evaluated. This aspect of the analysis of productivity is mentioned at this point, because the productivity model (which therefore includes the economics of computerisation and the Solow paradox) seems to rest on rather shaky theoretical grounds, despite the confidence in the orthodox approach in the US NIPAs and other OECD countries. This chapter analyses the way that the Cobb-Douglas function is actually used in the productivity literature, despite these reservations and critiques.

According to Hennings (1987:331), the link between the Cobb-Douglas function and index numbers is that capital is a "fairly homogenous and amorphous mass which could take on different forms" and thus "capital consisted of capital goods: but their aggregation into a more or less homogenous aggregate was considered an index number problem which could be solved in principle as well as in practice". It was the aggregation of capital that led to the so-called "Cambridge capital controversy", as mentioned earlier. The controversy does not appear to have been resolved yet.

The general form of the Cobb-Douglas production function is similar to the basic production function, and is written as:

$$Q = AK^{\alpha}L^{\beta} \qquad (\alpha > 0,\ \beta > 0) \qquad (1)$$

Various properties of the Cobb-Douglas function are discussed below. A discussion of these properties is included here because they pertain to the measurement of productivity and the Solow paradox.

For greater convenience, the Cobb-Douglas function can be converted into a linear form, using natural logarithms. Thus equation (1) can be written as:

$$\ln Q = \ln A + \alpha \ln K + \beta \ln L \qquad (2)$$

where ln = a natural logarithm.

Similarly, equation (2) can be expressed as rates of change or growth rate over a particular period, where the growth rate is denoted by an asterisk (*). Thus:

$$\ln Q^* = \ln A^* + \alpha \ln K^* + \beta \ln L^* \qquad (3)$$

Hence Q*, L* and K* denote the rates of change of output, labour and capital over a particular period respectively.

2.9. Returns to scale

Constant returns to scale are an important property of the Cobb-Douglas function. Returns to scale will be discussed in subsequent chapters, because the assumption of constant returns to scale can be a limiting factor in productivity analysis. The idea of increasing returns has been incorporated into growth theories by several researchers, such as Romer (1986) and others.

A function is said to be homogenous to degree $(\alpha + \beta)$. If $\alpha + \beta = 1$, the function is linear and homogenous and exhibits constant returns to scale. In the standard growth accounting model presented here, it is assumed that the production function exhibits constant returns to scale (OECD Manual 2001:128).

According to Allen (1973:50), with constant returns to scale, only one parameter is required, since $\alpha + \beta = 1$, so that $\beta = 1 - \alpha$ (0<α<1); and the function can be written as

$$Q = AK^{\alpha}L^{1-\alpha}$$

Under the long-run laws of production, returns to scale need not be constant, but may be increasing or decreasing. The determination of the scale of production is an empirical issue (Pearce 1992:376). If constant returns to scale apply, that is, $\alpha + \beta = 1$, then output Q will change in proportion to the change in both inputs K and L. If $\alpha + \beta < 1$, decreasing returns to scale apply and the increase in output is less than the proportional change in inputs; and if $\alpha + \beta > 1$, increasing returns to scale applies and the increase in output is larger than the proportional change in inputs (Glass 1980:215).

2.10. Elasticity of substitution

The elasticity of substitution measures the degree of substitutability between factors of production. The elasticity of substitution between factors is equal to unity when the production function under constant returns to scale is linear and homogenous (Allen 1973:51). Thus the elasticity of substitution for the Cobb-Douglas function is unity. This may not be a realistic assumption, because a study by Arrow et al. (1961:246) found evidence that the elasticity of substitution between capital and labour is typically less than unity.

Elasticity of substitution (σ) is defined as the change in the capital-labour ratio, K/L, divided by the marginal rate of technical substitution of labour for capital $MRTS_{LK}$ (Glahe & Lee 1981:421). The marginal rate of technical substitution is the rate at which one input must be replaced by the other input in order to maintain the same level of output (Schotter 1997:170). When σ = 1 (as with the Cobb-Douglas function), a 10% change in the $MRTS_{LK}$ will yield a 10% change in K/L.

Unity of substitution is one of the Cobb-Douglas function's main restrictions. The constant elasticity of substitution (CES) and translog functions relaxes this restrictive assumption.

Maddala (1979:309) states that the different functional forms of the production function differ in their elasticities of substitution. Significantly, according to Maddala (1979:309), the different functional forms do not produce significant differences in productivity measurement and other issues such as disequilibrium, measurement problems and aggregation problems are more important. The choice of functional form will not make much difference in productivity measurement (Maddala 1979:317).

2.11. Factor income shares and the distribution of the product

Barro and Sala-i-Martin (2004:30) contend that the behaviour of factor income shares is the key property of the Cobb-Douglas function. The marginal productivity theory of distribution, on which the theoretical determination of factor shares is based, is a cornerstone of neoclassical economic theory.

If the production function shows constant returns to scale and is linearly homogenous, then Euler's theorem holds. This theorem is also referred to as Euler's product exhaustion theorem (Koutsoyiannis 1979:478). Euler's theorem states that the value of output *Q* is exhausted in factor payments, if each factor, capital and labour, is paid the value of its marginal product. The marginal product of capital is equal to the rental price of capital; and the marginal product of labour equals the wage rate (Barro & Sala-i-Martin 2004:30). It follows that if each factor earns the value of its marginal product, then the sum of all the factor payments will be precisely equal to the total product. In other words, the product *Q* is attributable to the factors, labour and capital, without any surplus or deficit (Allen 1973:43).

Apart form the marginal theory of distribution, empirical analysis shows that relative shares of capital and labour in income have been relatively stable over time. However, according to Barro and Sala-i-Martin (2004:30), although the factor shares have been relatively stable in the USA , this is not the case in all countries.

In general, in the USA the shares for K and L in income have been calculated by the Bureau of Economic Analysis (BEA) and the results published in the NIPAs. This calculation will be discussed in chapter 4. In this calculation, in 2001, the share of labour was 72% and that of capital 28% in national income (in current dollars) in the USA.

Labour is the dominant factor of production, in the sense that wages represent about three-quarters of the national product and property incomes the remaining one-quarter (Samuelson 1980:502). Paul Douglas, one of the eponymous inventors of the Cobb-Douglas production function, found that labour's share was 0.75 in early studies of American manufacturing between 1899 and 1922 (Douglas 1948:6).

Other researchers have drawn comparable conclusions. Depending on their research focus, researchers estimate either the share of labour or the share of capital. Maddison (1987:659) estimates a capital share of 32% for advanced capitalist economies from 1960 to 1973. Maddison (1987:660, table 8) also provides a summary of four other estimations for industrial countries and finds an average of 40.3% over different post-Second World War periods. Collins and Bosworth (1996:154-6), in their study of economic growth in East Asia, estimated a capital share of 0.35.

Senhadji (2000:141) estimates the share of physical capital for 88 countries between 1960-1994 and finds that capital's share varies greatly across regions, with sub-Saharan Africa the lowest mean value (0.43) and industrial countries the highest (0.64). Generally, researchers have estimated the proportion to be between 70 and 75% for labour and 30 and 25% for capital.

Solow (1958), Kravis (1959) and other economists are not convinced that factor shares were constant. Arrow et al. (1961:225 & 246) found varying degrees of substitutability between capital and labour in 24 different manufacturing industries, but found it to be typically less that unity. However, Gollin (2002) found that, when appropriate adjustments to income-share calculations are made, the share of labour in income across countries varies between 0.65 and 0.80. This shows that factor shares are almost independent of levels of economic development.

As discussed above, factor shares are typically calculated from the NIPAs, but these may give inaccurate results. The accuracy of factor shares arose in the debate about the sources of growth of the East Asian countries and the so-called “Asian miracle”, discussed above (see also Nelson & Pack 1999; Krugman 1994b; Sarel 1997; Young 1995).

Senhadji (2000:152) and Sarel (1997:14) show that TFP’s contribution to output is highly sensitive to and depends on the share of capital: the higher α is, the lower the TFP contribution to growth is.

To improve the accuracy of the measurement of the factor shares Sarel (1997) provides alternative measures for its calculation. Apart from the “national accounts” and “regression” approaches, Sarel (1997:14-17) proposes a new method for the calculation of capital’s share in output. He argues that factor shares calculated from the NIPAs in East Asian countries are inaccurate and shows that TFP did indeed play an impressive role in the East Asian growth miracle, a view which contradicts earlier studies (see Krugman 1994b; Young 1995). Using the dual approach, Hsieh (1999, 2002) obtained similar results that technological progress did play a key part in East Asian growth. The above disagreements make it clear why Robinson (1934:398) referred to this theory as the “adding-up problem”.

These issues will also be explored in chapter 6.

2.12. Labour productivity, capital deepening and multifactor productivity

The equations in **section 2.8** can be restated to calculate labour productivity growth (LP*). *LP** is the difference between output growth and labour input growth and can be expressed as *LP** = *Q** − *L**. We assume constant returns to scale. By re-arranging equation (3) and discarding the natural log notation, one obtains

$$LP^* = Q^* - L^* = (1-\beta)(K^* - L^*) + A^* \qquad (4)$$

Since $(\alpha + \beta) = 1$, and $(1-\beta) = \alpha$,

$$LP^* = \alpha(K^* - L^*) + A^* \qquad (4.1)$$

Equation (4) shows that growth in labour productivity can be separated into two components. The first right-hand component in equation (4.1), $\alpha(K^* - L^*)$, accounts for capital deepening, which is adjusted for capital’s contribution to the production process by a weight of α. The second right-hand component, *A**, is a residual and accounts for MFP.

The fact that LP is the sum of capital deepening and MFP is a basic and fundamental result. Many productivity studies assume that the reader is familiar with this equation. It is also often assumed that productivity refers to LP; MFP is usually referred to as MFP or TFP, or as technical progress or similar derivations and synonyms.

Using equation (4.1) it can be shown that if the share (or factor weight) of capital (α) is relatively small, then labour productivity growth and multifactor productivity growth will be almost equal. If the capital-labour ratio is stable, labour productivity growth and multifactor productivity growth will be almost equal. However, labour productivity growth and multifactor productivity growth rates will diverge if the contribution of capital is significant and the capital-output ratio is not fixed (Gust & Marquez 2000:666).

The labour variable *L* is usually measured in labour hours; and the capital variable *K* usually measured in tangible capital stock, which may include land, although land is often ignored in the production process. The change in output that cannot be explained by changes in the contributions in labour or capital is denoted by *A**. This variable is therefore a residual because it is the remainder after the contributions of labour and capital have been subtracted from output. The residual *A** has been equated with multifactor productivity (MFP) and technical or technological progress. (Schreyer & Pilat 2001:131.)

MFP growth results from technical progress, technological advances and through improvements in production techniques and processes, rather than from increases in factor inputs. For example, a production process can be redesigned so that output increases while retaining the same number of machines, materials and workers as before (US Congress 2003:68). MFP is estimated to be the difference between the growth in output and the growth of the combined inputs of labour and capital.

Productivity can be defined as the ratio of a volume measure of output to a volume measure of input used – that is, it is the ratio of output (or real GDP) to the inputs that are used to produce that output. Similarly: "The rate of growth of total factor productivity is the difference between the rate of growth of real product and the rate of growth of real factor input" (Jorgenson and Griliches 1967: 249).

Productivity growth may imply that there is a net saving or cost reduction in the production process (NRC 1979:37). Productivity is thus a measure of the efficiency of production: it describes how efficiently input is converted into output. It follows that per capita income, for instance, will only increase when there is an increase in output per unit of input (Krugman 1994b).

This basic formula for multifactor productivity (A) reveals the interrelationship between output and input:

$$A = \frac{Q}{\alpha K + \beta L}$$

where Q is real output, K is capital input and L is labour input (NRC 1979:43).

Capital deepening means that the amount of capital per worker increases, in other words, the capital-labour ratio rises, so that labour productivity can be improved as more capital is available per worker (Schreyer & Pilat 2001:131).

The Cobb-Douglas production function is restricted in various ways, as the foregoing summary shows. Researchers have therefore sought more flexible forms of the production function. Examples of such forms are the CES and translog function, as mentioned above. The important translog function is reviewed below.

2.13. The translog production function

The transcendental logarithmic production function or translog production function is a generalisation of the Cobb-Douglas production function. Jorgenson, Gollop and Fraumeni (1987:31-68) show the importance of the translog function in productivity analysis.

The translog function is a quadratic function using natural logarithms:

$$\ln Q = a + \alpha \ln L + \beta \ln K + \gamma \ln L \ln K + \delta (\ln L)^2 + \varepsilon (\ln K)^2$$

where Q is output, L is labour, K is capital and a, α, β, γ, δ and ε are constants, and ln is the natural logarithm. If the parameters $\gamma = \delta = \varepsilon = 0$, the translog function reduces to the Cobb-Douglas form. When these parameters are nonzero, the elasticity of input substitution is also nonzero (Pearce 1992:124 & 434).

The translog function was introduced to test theories of production and estimate parameters (e.g. elasticities) under the minimum of *a priori* assumptions (Stern 1994:172). It has an advantage over the Cobb-Douglas form in that it has fewer restrictive properties and can be used to aggregate diverse inputs. This is a useful property because it enables disaggregation (or separability) between inputs, such as capital (equipment and structures) and labour, so that the possibility of substitution between these factors (and the elasticity of substitution between them) can be examined (Berndt & Christensen 1973:82 & 100).

In particular, the translog function relaxes the assumption of unitary elasticity of substitution. Factor substitution is unrestricted and “allows the elasticities of substitution among inputs to vary as input proportions vary”, a desirable property, which the Cobb-Douglas function lacks (BLS 1983:34).

2.14. Forms of technical change

The terms “technical change” and “technological change” (or progress) will be used interchangeably in this dissertation, although they do not mean exactly the same thing. Generally, technical change or progress means that more output can be produced from the same quantities of labour and capital involved in the production process (Pearce 1992:423). Since computerisation is a form of technical change, the precise nature of the change involved must be examined.

There are two main types of technical progress – embodied and disembodied. The two views differ on the transmission mechanism from technical change to economic growth. Disembodied technical change affects economic growth independently of capital accumulation, whereas embodied technical change requires investment to influence output. (Hercowitz 1998:217).

The two views have different implications for the analysis of productivity and the Solow paradox - the correct identification of the form of technical change involved in computerisation is analytically essential. In particular, because new technologies to produce capital goods have developed rapidly since the mid-1970s, the transmission mechanism of technological progress to output growth must be analysed and understood (Hercowitz 1998:217). Also, according to Schreyer and Pilat (2001:158), the distinction has significant implications, because embodied technical change is dependent on market transactions, whereas disembodied technical change is not.

The disagreement over the precise nature of the difference turned into a controversy, the so-called “embodiment” versus “disembodied” controversy. It originated in the 1960s when Solow and Jorgenson disagreed on the importance of capital-embodied technical change. The opposing views are articulated in Solow’s 1960 paper, *Investment and technical progress,* and Jorgenson’s 1966 paper, *The embodiment hypothesis*. Solow’s view was that embodied technological change is the dominant mechanism and consequently that investment is the key factor in growth (Hercowitz 1998:217). Jorgenson (1966:2), however, argued that the two types of technical change cannot be distinguished from the available data and that the transmission mechanism could therefore not be determined.

Finally, Denison (1964) argued that the embodiment hypothesis was unimportant, because the changes in the age distribution of the capital stock have a minor impact on output growth (Hulten 1992b:964).

2.15. Disembodied technical change

Disembodied technical change is a relatively simple interpretation of technical change, which does not specify a transmission mechanism. It “applies equally and alike to all resources of men and machines in current use” and appears costless, like "manna from heaven" (Allen 1973:236).

It occurs independently of capital accumulation or any other economic variables (Pearce 1992: 110).

According to Solow (1960:91) this form of technical change was something like “a way of improving the organisation and operation of inputs without reference to the nature of the inputs themselves. The striking assumption is that old and new capital equipment participate equally in technical change.”

According to Mokyr (1990a:7), technological change, in this interpretation, is a “part of economic growth that cannot be explained by more capital or more labour, and that thus must come to be regarded as a free lunch” and affects output growth independently of capital accumulation (Hercowitz 1998:217).

Technology is generally considered to be disembodied, which must mean that technological diffusion should be almost instantaneous (Atkeson & Kehoe 2001:1). However, this is not so, as the slow diffusion of the use of the adoption of electricity in the production process shows (see David 1990).

In terms of computerisation, disembodied technical change is not caused by the technological sophistication of computer equipment, but by the networking and interconnectedness that the internet and e-mail make possible, allowing people to work more productively (OECD 2004:11).

2.16. Embodied technical change: technical change embodied in new investment

Solow (1960:91) proposed that an alternative model of technical change be found, since the disembodied formulation “… conflicts with the casual observation that many if not most innovations need to be embodied in new kinds of durable equipment before they can be made effective. Improvements in technology affect output only to the extent that they are carried into practice either by net capital formation or by the replacement of old-fashioned equipment by the latest models, with a consequent shift in the distribution of equipment by date of birth.”

According to Denison (1962:91): “To speak of technical progress embodied in capital is simply to refer to changes in the quality of capital goods.” Allen (1973:237) notes that embodied technical progress applies only to “certain tranches of capital equipment, usually machines produced and installed currently, together with the associated labour crews. Capital becomes essentially a mixed stock of different ‘vintages’. Machines of different vintages are different in kind, as new machines are more productive than older similar machines.”

Under embodied technical progress, “manna from heaven” drops only on certain types of capital equipment, typically the newest, and also on certain sections of the labour force (Allen 1973:254). The specific ages or vintages of capital and humans must be distinguished. In short, older machinery does not benefit from embodied technical change. Thus, the age of capital equipment, or vintage capital, plays the more important role in the analysis. Embodied technical change can thus be described as investment-specific technical change (Greenwood, Hercowitz & Krusell 1997).

Labour, too, can be distinguished by age and training. Thus, according to this view, neither capital nor labour is treated as homogenous.

Embodied technical change requires investment to affect output (Hercowitz 1998:217). Hence technical progress is dependent on new capital and technical progress is embodied in new capital.

Computer equipment is generally classified as capital equipment. The silicon chip represents technical progress because it has made many technologies and hence capital obsolete since it requires a new investment in different forms of capital (Pearce 1992:125).

Hercowitz (1998:223), in his review essay on the controversy, concludes “that ‘embodiment’ is the main transmission mechanism of technological progress to economic growth”, thus lending support to Solow’s view. Similarly, Greenwood et al. (1997:359) concluded that 60% of post-war productivity growth is attributable to investment-specific (or embodied) technological change.

2.17. Neutrality of disembodied technical change

Allen (1973:237) discusses the issue of the neutrality of disembodied technical change and suggests that although neutral technical progress shifts the production function, it does not alter the balance between capital and labour – hence it is neither capital saving nor labour saving.

Non-neutral technical change can therefore be classified as either labour saving or capital saving. Inventions can be labour saving or capital saving, but if the invention does not save relatively more of either input, but generates the same amount of output, the invention is called neutral or unbiased (Barro & Sala-i-Martin 2004:52).

According to Hahn and Matthews (1964:825), the purpose of defining neutral technical change is to get a sense of those characteristics that will not change the balance between capital and labour. Because technical change causes a shift of the entire production function, a new problem arises “in deciding which point on the old production function to compare with which new point on the new one” (Hahn & Matthews 1964:825).

Consequently, alternative definitions of neutral technical change were formulated to deal with the problem. There are three types of neutral technical change: Hicks-neutral, Harrod-neutral and Solow-neutral technical progress.

2.18. Harrod-neutral technical progress

According to Allen (1973:237), Harrod-neutral technical progress occurs when the shift of the production function over time is of the form

$$Y = F(K, \alpha L)$$

where $\alpha = \alpha(t)$. (Y rather that Q is used when output is the same as income and there is no lag between output and income [Allen 1973:11 & 236]). This form of technical change denotes an "all-round increase in the efficiency of labour" (Allen 1973:237-8) because it is labour augmenting, since it corresponds to an increase in the labour force, "so that one man does as much as two men used to do, then as much as three men, and so on" (Allen 1973:238).

According to Blaug (1992:172), Harrod-neutral technical progress is defined as points in the growth process where the *capital to output ratio* remains unchanged at a given rate of interest and constant relative factor prices (i.e. wages and profits). This implies greater quantities of or more efficient labour, leading to a change in labour's coefficient in the production function (Pearce 1992:423).

More specifically, the Harrod-neutral production function, is written as:

$$Y = F[K, L \cdot A(t)]$$

where *A(t)* is an index of technology. It is referred to as labour-augmenting technical progress because output is increased in a similar way to an increase in the stock of labour (Barro & Sala-i-Martin 2004:52).

Barro and Sala-i-Martin (2004:53) argue that technological progress must necessarily be labour-augmenting in a model with a steady state, where all the variables grow at constant rates in the long run.

2.19. Solow-neutral technical progress

According to Allen (1973:239-40) Solow-neutral technical progress applies when the shift of the production function over time is of the form:

$$Y = F(\alpha K, L).$$

This form is more relevant to embodied or vintage-type technical progress (Allen 1973:239), as discussed above.

Solow-neutral technical progress is defined as points in the growth process where the *labour to output ratio* remains constant (Pearce 1992:423). More specifically, the Solow-neutral production function is written as

$$Y = F[K \cdot B(t), L]$$

where *B(t)* is an index of technology. The function is capital augmenting because production is increased by technological improvements in a similar way to an increase in the capital stock (Barro & Sala-i-Martin 2004:52).

2.20. Hicks-neutral technical progress

According to Allen (1973:239-240), Hicks-neutral technical progress obtains when the shift of the production function over time is of the form:

$$Y = \alpha F(K, L).$$

This was the first form of technical progress to be proposed and can be characterised as “manna from heaven” in the most obvious sense. It fits in neatly with the idea of neutrality (Allen 1973:239). Hicks-neutral technical progress depends only on time and is thus independent of the factor inputs (Jorgenson et al. 1987:35).

Hicks-neutral technical progress is defined as points in the growth process where the *capital to labour ratio* remains unchanged at constant relative factor prices (Blaug 1992:172). Since the ratio of the marginal product of capital relative to labour is unchanged, the share of output allocated to capital and labour remains the same (Pearce 1992:423).

More specifically, the Hicks-neutral production function (which includes time variable *t* to reflect the effects of technological progress) is written as:

$$Y = F(K, L, t) = T(t) \cdot F(K, L)$$

where *T(t)* is an index of the state of technology (Barro & Sala-I-Martin 2004:52).

According to Gundlach (2001:14), the growth accounting literature uses Hicks neutrality as the standard concept. Also, the OECD Manual (2001:19, box 1) states that the index number approach implies Hicks neutrality.

Gundlach (2001), analyses the differences between the Solow, Hicks and Harrod interpretations of economic growth. The difficult question is: How does a production function shift from one state to another? (Gundlach 2001:8.) Different types of shifts require different interpretations of factor accumulation and technological change (Gundlach 2001:9).

2.21. Conclusion

Norsworthy (1984:309) discusses the different approaches used by three prominent researchers who work within the growth accounting framework, namely Kendrick, Jorgenson and Denison. He points out that research has revealed various shortcomings in the growth accounting approach to productivity analysis. However, despite these shortcomings, the neoclassical framework provides the only basis on which the factors of production can be aggregated to measure multifactor inputs (Norsworthy 1984:310).

Also, Norsworthy (1984:327) notes that the growth accounting framework is a "filing system that is *complete*, in the sense that all phenomena that affect economic growth must do so through input factor quantities, relative factor intensities or total factor productivity growth, either simply or in combination".

In subsequent chapters, an interpretation of the productivity slowdown and the computer paradox is conducted within the growth accounting framework. However, the growth accounting framework uses the index number approach to provide the actual measurements of output, inputs and productivity. This approach is the topic of the next chapter.

3. CHAPTER 3: INDEX NUMBERS AND PRODUCTIVITY

3.1. Overview

This chapter deals with four interrelated issues: (1) the economic theory of index numbers; (2) a brief review of index numbers and the index number problem; (3) quality adjustments and the measurement of inflation and real output; and (4) the construction and use of index numbers for the calculation of hedonic price indexes for computers. The hedonic method is used estimate the effects of quality changes on prices (ILO 2004:446).

These issues have direct implications for the measurement of productivity and the Solow paradox. Index numbers affect the measurement of computerisation in two important ways: computer prices tend to fall rapidly; and computer output is difficult to measure.

This chapter is not intended as an introduction to index numbers or index number theory, and assumes that the reader is familiar with the construction and calculation of basic index numbers. Its aim is to discuss the problems encountered in the measurement of computerisation and the ICT sector.

3.2. The economic theory of index numbers

The use of variables based on index numbers is widespread and influences many economic and business investment decisions, as highlighted by Diewert (1987:767): "Index numbers are used to reduce and summarize … (the) overwhelming abundance of microeconomic information. Hence index numbers intrude themselves on virtually every empirical investigation in economics."

The theory, construction and application of index numbers is fundamental to the productivity paradox, as it is to many other fields of economic analysis. Index numbers are the main operational tool for productivity analysis, because they make possible the integration of economic theory and the national accounts (Schreyer & Pilat 2001:131). Economic variables such as inputs and outputs are measured by means of index numbers. The measurement of quality changes in particular plays a vital part in the accuracy of index numbers.

Price indexes in particular, affect the accuracy of productivity measurement (Eldridge 1999:35). For example, the measurement of inflation, which is used to deflate nominal output to obtain real output, is also based on index numbers. If inflation is not correctly measured, real output and hence productivity will not be correctly measured, because real output is the numerator in the calculation of productivity.

Marris (1958:186-187) argues that prices and money play a major part in economic analysis, but money, the measuring rod of value, itself changes in value (Marris 1958:188): "Index numbers, then, are largely devices for mitigating deceptions caused by changes in the value of money". The central theoretical problem of index numbers is "to pull down the veil of money."

According to Motley (1992a:7), the economic theory of index numbers "begins with the assumption that the quantities of individual goods and services that we observe consumers buying are those that maximize their satisfaction (or utility) given their incomes and prices they face."

Two issues feature prominently in the debate over index numbers, namely the principles of the construction of weighted aggregates, and the relevance of the particular weights applied in relation to a measure of public welfare (Marris 1958:188).

The construction of index numbers is a problem of economic theory as well as of statistical technique. Frisch (1936:1) argues as follows: "Indeed, all discussions about the "best" index formula, the "most" correct weights, etc., must be vague and indeterminate so long as the meaning of the index is not exactly defined. Such a definition cannot be given on empirical grounds only but requires theoretical considerations."

According to Allen (1975: 37), their construction must be aligned with the goal they are expected to achieve; there "can be no 'measurement without theory' in economics and the social sciences as in the physical sciences."

3.3. Index numbers: a special kind of average

Moroney (1956:48) states that index numbers are single numbers that summarise or aggregate a range of values over periods of time and "are really nothing more than a special kind of average."

The various types of indexes are reviewed briefly in order to understand their use in the system of national accounts and their relevance to the measurement of productivity and the Solow paradox. Several aspects of index numbers that are relevant to the subsequent discussion of the productivity paradox will be surveyed.

Several issues are pertinent to productivity measurement in general and some relate more to the analysis of computerisation – however, the two issues are interrelated. The methodology of hedonic prices and their application to IT are reviewed.

Although the index number approach is the standard approach used for productivity measurement, the econometric approach is also followed. This dissertation will focus exclusively on the index number approach, because it is closely associated with Solow's work, even though there are synergies between the two approaches (Schreyer & Pilat 2001:131). The economic theory of index numbers, as developed by Caves, Christensen and Diewert (1982: 1393) also acknowledges Solow's contribution.

There are two basic types of indexes: price indexes and quantity indexes. Output (GDP) is a quantity index, while inflation is a price index. The most familiar price index numbers are the consumer price index (CPI) and the producer price index (PPI).

Although only two variables, prices and quantities, are used to construct index numbers, such as price indexes (e.g. consumer inflation) or quantity indexes (e.g. real GDP growth), they are interrelated. According to Allen (1975:1): “Index numbers come in pairs in economic theory, one of price and the other a matching one of quantity. In economic practice, they tend to be found paired off in this way. Sometimes one or the other is used alone; but there is almost always a mate to it in the background.”

3.4. The index number problem

An understanding of index numbers and the index number problem is essential for the analysis of the Solow paradox, since references to index numbers appear frequently in the productivity literature (Allen 1975).

Index number problems play a critical role in the calculation of productivity (Diewert 1987). Such problems do not arise when dealing with nominal quantities (Prescott 1997:11). Real output is measured by price indexes which are based on a fixed base year. Thus if products (like computers) undergo large price changes, the index is biased (Oliner & Wascher 1995:19-20). It is the conversion of nominal values to real values that creates the index number problem.

The index number problem relates to the problem of aggregation and arises “when an attempt is made to compare two sets of variables at two points in time using a single number since there are many different ways of aggregating variables into a single measure” (Pearce 1992:199).

Put differently, the index number problem is: "How to construct an aggregate quantity (or price) measure of two or more components when their relative prices (or quantities) are changing" (Dean, Harper & Otto 1995:28-29). Therefore, depending on the methodology used (i.e. a base-weighted index compared to a current-weighted index, or other indexes), different answers may be obtained using the same price and quantity values.

The problem applies to computers (classified as manufacturing output in the US System of National Accounts) in particular, whose prices have been falling rapidly and continuously since the 1970s.

3.5. Index number bias

Although index numbers are intended to improve accuracy in economic calculations, they also introduce many types of bias. The International Labour Organisation (ILO 2004:443) defines the

CPI bias as a “systematic tendency for the calculated CPI to diverge from some ideal or preferred index, resulting from the method of data collection or processing, or the index formula used.”

The calculation of real GDP when the base year shifts illustrates one type of index number bias. In the case of base weighted indexes, the further back the base year, the higher the GDP growth rate will be. Whelan (2000b:4-5) shows the calculation of the US real GDP growth rate for 1998 using different base years: “The growth rate of fixed-weight real GDP in this year was 4.5% if we use 1995 as the base year; using 1990 prices it was 6.5%; using 1980 prices it was 18.8 percent; and using 1970 prices is was a stunning 37.4 percent! …[because] Categories with declining relative prices tend to have faster growth in quantities”. This is further discussed in **section 5.13**.

Although there are several types of index number bias, the types of bias that distort productivity and computerisation measurement will be discussed here.

There are several types of bias in the measurement of inflation, such as substitutions bias (or the cost of living bias [see ILO 2004:444]); representativity bias (see ILO 2004:448); outlet bias; and calculation bias. Inflation bias affects productivity and computers directly. The Boskin Commission (1996) published a comprehensive report on inflation bias in the US consumer price index. The National Research Council (2002) subsequently published a comprehensive report on conceptual and statistical issues in developing cost-of-living indexes (COLI).

Index number bias, applied to computerisation and the ICT industry, is discussed more fully below. The index number problem and the productivity paradox will be evaluated in chapter 6.

To illustrate how the use of different index formulas causes real output to diverge, Filardo (1995:57) constructed a fictitious two-sector economy, in which prices decline rapidly in the “computer” sector but are stable in the “other” sector. His calculations are given below.

Table 3.1: A fictitious economy: the national accounts

	Economic data			
	1987	1992	1993	1994
$P_{computer}$	100	45	35	30
P_{other}	100	100	100	100
$Q_{computer}$	1	1.7	2.8	3.8
Q_{other}	100	110	112	116

Source: Filardo (1995:57)

On the basis of the data in **table 3.1**, the following real growth rates are obtained:

Table 3.2: A fictitious economy (contd.): real growth rates		
	1993	1994
Fixed-weighted 1987 base	3.1	4.1
Chain-weighted base	2.5	3.6
Fixed-weighted 1992 base	2.5	3.6
Substitution bias	0.6	0.5
Source: Filardo (1995: 57**)**		

Since the relative price of computers ($P_{computer}$) has fallen, the quantity of computers purchased ($Q_{computer}$) has increased almost fourfold. However, since the price of "other" (P_{other}) has remained stable, the quantity of "other" (Q_{other}) purchased has increased marginally, between 1987 and 1994. Consumers generally purchase larger quantities of goods and services whose prices have fallen. Real output growth in 1993 and 1994 is overstated by the fixed-weighted 1987 base index, because the computer industry is too heavily weighted (by price) in 1987. The chain-weighted index and the fixed-weighted 1992 index yield the same growth rates. This overstatement is referred to as the substitution bias (equal to the difference between the two fixed-weighted indexes) and amounted to a 0.6 percentage point in 1993 and a 0.5 percentage point in 1994 (Filardo 1995:58-59). These problems and different types of indexes will be discussed in more detail below.

3.6. Overview of index numbers

Several types of index numbers are relevant to productivity measurement and technological change. The most widely used index numbers are the Laspeyres, Paasche, Fisher, Törnqvist and Divisia indexes. These, as well as other important forms, will be reviewed below.

3.6.1. The Laspeyres index

The Laspeyres index number, formulated in 1864 by Etienne Laspeyres, is a base-weighted index whose weights are derived from values obtained in the base year, which is typically a few years in the past (Bannock et al. 1989:239). The problem is that the base year weights, which remain constant, can quickly become outdated and the index can therefore be biased. The Laspeyres index suffers from substitution bias and has an upward bias, because of the effects of substitution (Motley 1992a:6).

3.6.2. The Paasche index

The Paasche index is a current-weighted index, formulated by H. Paasche in 1874. Its weights are derived from values in the current period rather than the base period in the past (Bannock et al. 1989:307). The index also suffers from substitution bias, but has a downward bias, because of the effects of substitution (Motley 1992a:6).

Neither the Laspeyres nor the Paasche index is adequate for economic analysis, mainly because of the basis on which the weights in the index are changed, which is not frequently enough. Government statistical agencies in the developed world tend to conduct household surveys only every five years or so to establish consumption patterns for the consumer price index. For example, in the measurement of consumer price index, consumption habits may change over a short period of time (as new products are introduced and products no longer desired disappear or see their consumption decline) and a base-weighted index will not capture current consumption patterns. A current-weighted index, however, will not sufficiently capture long-term changes (Numbers Guide 1991:24).

3.6.3. The Fisher ideal index

The Fisher ideal index is the geometric average of the Laspeyres and Paasche indexes (Motley 1992a:7). Its value lies between the Laspeyres and Paasche indexes by construction (Motley 1992a:8). The meaning of “ideal” will be discussed below.

3.6.4. The Törnqvist index

This widely-used index was developed by Törnqvist in 1936 to calculate the Bank of Finland’s consumption price index, with the intention of speeding up the calculation of the cost of living index. The weighting system indicated “the share of the respective class of goods in the total value of consumption” (Törnqvist 1936:27).

Motley (1992a:7) defines the Törnqvist price index as “the weighted geometric average of the increase in individual commodity prices, with weights equal to the average expenditure shares in the base period t and the current period s”. Its value typically lies between the Laspeyres and Paasche indexes by construction (Motley 1992a:8). The ILO (2004:449) states that it is a symmetric as well as a superlative index (see below).

The Fisher ideal index and the Törnqvist index give similar results in most cases and can be used interchangeably (Motley 1992a:8).

The translog production function (discussed in chapter 2) is consistent with the Törnqvist index (BLS 1983:34). The translog function takes into account the fact that “input factor prices and quantities observed in a given year are most relevant for computing weights in that year.” (BLS 1983:34). For example, if the price of capital increases relative to the cost of labour, firms will use relatively less capital and more labour. Therefore, as the relative price of capital rises, the relative quantity used falls. When input indexes are calculated, the weights used are based on the factors' average cost shares. These cost shares or weights may have changed as the price of capital has risen; but a base-year index captures only the quantity change, whereas the Törnqvist index captures both changes.

3.6.5. Fixed-weight indexes

A fixed-weight price index holds the quantities fixed which were obtained for some selected (base or current) year. According to this approach, the basket of goods used in the index is thus identical in all years. The Laspeyres and Paasche indexes are examples of fixed-weight indexes. Fixed-weighted indexes possess one important type of bias, the substitution bias, which makes them undesirable for economic, particularly CPI, analysis. According to Triplett (1975:22): "… when substitution occurs, the Laspeyres index (or any other fixed-weight formula) will, because it holds weights constant, overstate the change in the true cost of living …That is, the Laspeyres index overweighs commodities whose prices rise most rapidly because *consumers will cut their consumption of those commodities (substituting other goods for them), even if real income remains unchanged*" (Italics in the original).

Since these indexes use a fixed set of quantities, the quantities in the base period (as in the Laspeyres index) become progressively outdated and thus of little relevance to the later periods to which prices are being compared. The base period weights have to be updated continuously to maintain relevance, thus creating a new CPI series (ILO 2004:11).

The problems associated with fixed-weight indexes can be improved by the use of chain indexes. Chain indexes provide a rolling comparison between the base and current years by using all the data that have cumulated up to the current year (Allen 1975:177). The chain index in turn can be refined by the integral index varying continuously over time (Allen 1975:177). Chain and continuous (Divisia) indexes will be discussed further below.

3.6.6. Ideal, exact and superlative indexes

The term "superlative" index was defined by Fisher (1922), who devised several index number tests, based on whether or not an index possesses certain desirable statistical qualities. These quality tests are beyond the scope of this dissertation and are reviewed by the ILO (2004) and Ruist (1968:155-156).

Fisher (1922) rated only four indexes as "superlative". Superlative price indexes (1) used quantities in the base as well as the current year; and (2) used geometric averages, rather than arithmetic averages. Fisher's ideal index (also a superlative index) is the geometric average of the Laspeyres and the Paasche indexes (Ruist 1968:156).

Exact and superlative index numbers were further defined by Diewert (1976). A small class of index numbers can be classified as superlative. Superlative index numbers are desirable in the calculation of the CPI, because they can be expected to approximate the cost of living index (COLI). The COLI is discussed below.

According to Motley (1992a:7), exact indexes "measure changes in the true cost of living (that is, the cost of obtaining a certain level of satisfaction) in terms of the observable prices and quantities of individual goods and services", so that "price and quantity observations provide information about utility levels". An index is an exact index if it is equal to the true cost of living index in relation to consumer preferences expressed in a particular functional form (ILO 2004:449).

Symmetric indexes attach equal importance to price and expenditure data in both of the periods being measured (ILO 2004:3 & 449). The Fisher and Törnqvist price indexes are examples of superlative indexes. The Fisher ideal index and the Törnqvist index are two vital and widely used exact indexes.

3.6.7. Chain indexes

The chain index is simply a frequently reweighted index (Hulten (2000:7). More comprehensively it is "an index number series for a long sequence of periods obtained by linking together index numbers spanning shorter sequences of periods" (ILO 2004:444). Generally, indexes are calculated at regular intervals, and chain indexes link these together in a series of index numbers. The use of chain indexes was suggested by Marshall in 1887 (Ruist 1968:156).

When several Laspeyres indexes are linked in a series, a measurement problem arises. For example, if annual CPI indexes between 1990 and 2000, with 1990 as the base year, are constructed, a comparison between inflation in 1998 and 1999 is flawed, because the quantities consumed in 1990, which are outdated, are used as the basis of comparison. Chain indexes seek to overcome this problem.

The chain-weighted indexes are Fisher ideal indexes (where the base years change annually) with adjacent years as bases (Filardo 1995:57; Landefeld & Grimm 2000:19). Chain-weighted or chain-type indexes minimise the substitution bias.

Chain-type indexes were introduced into the US NIPA to calculate changes in real output and prices in 1996 (Parker & Triplett 1996:37). This resolved the substitution bias as well as the bias that resulted from updating the base period. The introduction of chain indexes resulted in a reduction of real GDP growth in all periods (Parker & Triplett 1996:38).

3.6.8. The Divisia index

The Divisia integral index, or Divisia index for short, is used to define an index that varies continuously over time (Allen 1975:178-80). This index was devised the French economist F. Divisia in 1925, who (Balk 2000:2)

> presented a novel solution to the problem of splitting a value change into two parts, a part due to prices and a part due to quantities. …The novelty of Divisia's indices was that, as functions of continuous time, they take into account the prices and quantities of all, infinitely many, intermediate periods. Thus a Divisia index number is not only dependent on the initial and terminal points of the time interval considered, but will as a rule depend on the entire path that the prices and quantities belonging to an economic aggregate under consideration have taken.

The index can be calculated directly from input quantities and prices and output quantities and prices (Baumol et al. 1989:234). However, in practice, chain indexes are regarded as sound approximations for Divisia indexes (ILO 2004:445).

The Divisia index is considered appropriate for the measurement of technological change. Solow introduced the Divisia quantity index in his seminal 1957 paper for the measurement of productivity growth (Balk 2000:4). Hulten (1973:1017) affirms that "In his 1957 article, Solow … showed that, under certain circumstances, it is the natural way of indexing technical change." Hulten (1973:1017) points out that many other researchers have made use of this index to measure productivity change, such as Denison (1962 & 1967) and Kendrick (1961).

Despite its advantages, the Divisia index suffers from a number of restrictive assumptions, such as constant returns to scale (Baumol et al. 1989:233-234), which will be discussed in chapter 6, in which the major explanations of the productivity paradox will be analysed.

3.6.9. Malmquist index

Caves et al. (1982) use the Malmquist index for input, output and productivity measurement. The index is based on discrete data points over time, instead of on a continuous function of time. Under constant returns to scale, the Malmquist index reduces to the Törnqvist index (Caves et al. 1982:1394).

3.7. Hedonic indexes

Hedonic methods are applied extensively to computer and peripheral equipment in the NIPAs of the USA and other OECD countries. This aspect of index number theory is therefore of the utmost importance to the measurement of productivity and the role of computers in the productivity slowdown.

Hedonic techniques are econometric analyses which seek to separate quality changes from price changes in a price index. Unless quality changes can be quantified, they cannot be distinguished from price changes. This problem has been regarded as one of the most serious defects in price indexes (Griliches 1961:55).

Hedonic techniques have their origin and theoretical basis in consumer theory, which was pioneered by Lancaster (1966), and subsequently refined by Rosen (1974). However, the use of hedonic methods dates back to 1928, when Waugh examined quality factors influencing vegetable prices, and to 1939, when Court published a paper on hedonic techniques applied to the US automobile industry (see Moulton 2001:2). The econometrician Griliches (1961) was one of the pioneers of hedonic techniques, which he used to adjust price indexes for quality changes to the price of automobiles. Also, in the 1960s, the US government instigated the Stigler Commission to investigate inflation and the quality change bias in the US national accounts.

These techniques have gradually been adopted by the US statistical agencies. The first US agency to use hedonic methods was the Bureau of the Census, which deflated single-family houses under construction using a sales price index, starting in 1968 (Moulton 2001:3).

More recently, the accuracy of price indexes, particularly the CPI, was re-examined, following the remarks by the Federal Reserve Chairman, Alan Greenspan, in 1995 that the CPI is overstated and the subsequent instigation of the Boskin Commission (1996) in 1996 to examine possible CPI bias (Hulten 2003:5). Following these developments, the National Research Council Committee on National Statistics published a comprehensive review of cost-of-living and price indexes in 2002 (NRC 2002). Quality change and hedonic methods are examined in detail in the NRC report (NRC 2002:106-154). All these events are closely related to the use of price hedonics in the calculation of the CPI.

Since consumers perceive goods and services as a bundle of characteristics, the hedonic approach is also called the characteristics approach, and (Griliches 1971:4)

> is based on the empirical hypothesis … which asserts that the multitude of models and varieties of a particular commodity can be comprehended in terms of a much smaller number of characteristics of basic attributes of a commodity … and that viewing the problem in this way will reduce greatly the magnitude of the pure new commodity or “technical change” problem, since most (though not all) new “models” of commodities may be viewed as a new combination of “old” characteristics.

Hedonic functions and indexes are interrelated: hedonic functions define the relations between prices of goods and services and the quantities of characteristics embodied in them; whereas hedonic indexes are built on the information from hedonic functions (Triplett 1987:630-633).

It should be noted that hedonic techniques are open to criticism: although the automobile can be measured in terms of measurable characteristics such as horsepower and weight, the consumer may not care about these characteristics, but value the car in terms of the "ride" and "handling" characteristics, which are difficult or impossible to measure (Bresnahan & Gordon 1997:20).

Hulten (2003:9) reviews price hedonics critically and finds many problems are associated with the hedonic method; although some of the problems are the usual ones associated with statistical techniques. As in the NRC report (2002:141, recommendation 4-3), which advocates "a more cautious integration of hedonically adjusted price change estimates into the CPI", Hulten (2002:12) favours a conservative approach, despite hedonics being the most promising method to account for quality changes. Ortiz (1999:12-3) also sounds several warnings.

Despite these reservations, the use of hedonic methods is expanding in the official statistics of the USA and has indeed accelerated over the last 10 years (see Moulton 2001). In the USA hedonic techniques were used in 10 NIPA components in 2001 (**table 3.3**).

Table 3.3: Hedonic inventory: NIPA prices that reflect hedonic techniques

(2001)	USD billion	% of GDP
Gross Domestic Product	10 128.0	
Total hedonic components	2 257.5	22.29%
- Computers and peripheral equipment*	246.8	2.44%
- Software*	90.4	0.89%
- Structures	552.7	5.46%
- Telecommunications*	32.1	0.32%
- Photocopiers	2.8	0.03%
- Audio & Video	50.2	0.50%
- Apparel	239.3	2.36%
- Household appliances	30.8	0.30%
- Rent	1 009.4	9.97%
- Education writing equipment	3.0	0.03%

Source: BEA (2004); Note: * ICT industries.

As indicated in the above **table 3.3**, in 2001 hedonic techniques were applied to NIPA components which amounted to 22.3% of GDP, and to ICT industries (computers and peripheral equipment, software and telecommunications) which amounted to 3.65% of GDP.

3.8. Indexes and quality change

As stated above, the main reason why index numbers are reviewed here is that they are potentially biased and this could help explain the Solow paradox. It is often claimed that the measurement of inflation is inaccurate because quality changes of goods and services (which is usually understood to be quality improvements) are not measured accurately. This has been referred to as the "quality change bias".

There are two types of quality errors: the failure to identify a quality change in a good or service and the failure to make the correct quality adjustment to the identified change. In principle, quality bias can be in either direction: upwards or downwards (Moulton & Moses 1997:306).

Inflation is therefore overstated to the extent that quality improvements are understated. In turn, the overstatement of inflation results in the understatement of productivity, because real output is also understated. The claim makes economic sense because if the price of a good or service increases by 10%, but if this price increase is accompanied by a quality increase of the same magnitude, there has been no real price increase. Similarly, if the price of a good or service increases by 10% and quality improves by 7%, there is a 3% actual price increase. Thus all or part of the price changes can be explained by quality changes. The trick is to distinguish between technological change or progress and pure price increases or inflationary pressures. Hedonic models are used to overcome the problem of quality change bias.

This concern is not new. Zvi Griliches, one of the pioneers of hedonic price indexes, stated the following, which appeared in Price Statistics of the Federal Government, published in 1961 (Griliches 1961:55): "If a poll were taken of professional economists and statisticians, in all probability they would designate (and by a wide majority) the failure of the price indexes to take full account of quality changes as the most important defect in these indexes."

Much of the disagreement focuses on the measurement of real GDP (the output quantity index) because it is an inflation-adjusted or deflated variable. The measurement of inflation has been under scrutiny and its accuracy examined by the Advisory Commission to Study the Consumer Price Index (also known as the Boskin Commission) which published its findings in 1996. The commission came to the conclusion that, on average, inflation had been overstated by about 1.1% over an extended period. Of this total, 0.4% was attributed to substitution bias; 0.1% to outlet bias; and 0.6% to quality and new goods bias. Quality changes and the introduction of new goods thus accounted for 55% of the overall bias, whereas substitution and outlet biases accounted for 36% and 9% respectively.

The measurement of inflation is relevant to the Solow paradox, because nominal output (the productivity numerator) is deflated by some measurement of price increases (inflation) to arrive at real output. Clearly this can have a major influence on the outcome. If inflation is overstated (as has been claimed), real GDP will be underestimated and hence productivity too. Much of the productivity debate has been around the measurement of output, as opposed to input.

Gordon and Griliches (1997) provide a concise overview of quality change and new products in relation to the concept of a cost-of-living index (COLI). The COLI refers to “a comparison in two time periods of the minimum expenditure required to achieve the same level of well-being” (Gordon & Griliches 1997:84). In a collection of essays on the economics of new goods by Bresnahan and Gordon (1997:2), the authors note in their Introduction that there is a close link between the COLI and contribution of new goods to consumer welfare.

3.9. Indexes and the introduction of new products

Although the economics of new goods is discussed more in the context of the consumer surplus, new goods also affect productivity and computerisation, because “a computer capable of completing a previously infeasible task is a new good” (Bresnahan & Gordon 1997:23).

The index number problem also appears with the introduction of new goods in a price index. There are two types of new products bias: the failure to include new products without a long delay, and the failure to account for the consumer’s surplus (i.e. the net welfare benefit to the consumer) emanating from the new product (Moulton & Moses 1997:306).

Generally, a new good is introduced into a price index by estimating a “virtual price” or the reservation price, a price which sets consumer’s demand for the product just equal to zero prior to the introduction of the good (Bresnahan & Gordon 1997:21; Moulton & Moses 1997:306).

The quality bias and the new product bias are not separate biases, because the consumer surplus resulting from the introduction of the new good should capture the price decline early in the product’s life cycle. The new product bias is usually upward (Moulton & Moses 1997:306).

3.10. Hedonic indexes and ICT

Several studies have applied hedonic techniques to the problem of price measurements in computerisation and have examined the quality adjustments that are made in the national accounts for computers. The main tool for making quality adjustments for computers is the application of hedonic methods. For example, Berndt et al. (1995:266) found that, taking quality changes into account (using hedonic methods) for personal computers, prices fell by about 30%

per year between 1989 and 1992. They found different rates of annual price declines for mobile computers (24%) and desktop computers (32%).

One of the earliest studies of the economics of computers is by Chow (1967:1130), who found that the stock of computers grew by about 78%, whereas computer prices fell by about 20% per year between 1954 and 1965. Chow (1967:1120) does not use hedonic techniques, although he employs three basic characteristics in his calculations: "multiplication time, memory size, and access time". Chow (1967:1121) considers only computer hardware in his study, but argues that software characteristics are also important for analysis.

Gordon (1987) examined the post-war evolution of computer prices and finds that hedonic techniques calculated that the prices of personal computers declined by 19.8% between 1951 and 1984. In a study of semiconductor prices, Grimm (1998:8) found that the price index of memory chips declined by an average of 37% per annum from 1975 to 1985 and by 20% from 1985 to 1996; and the price index for microprocessors by 35% from 1985 to 1996. Landefeld and Grimm (2000:19, table 2) provide a summary of various studies that have made quality adjustments to computer and equipment prices. The quality-adjusted estimations vary from a decline in prices of between 14 and 40% per year. However, since 1995, up to about 1998, the rate increased to between 30 and 40% per year. Moulton (2001:5) states that computer price indexes calculated by the BEA fell by 17.5% per year between 1959 and 2000. Chwelos (2003:199) found that between 1990 and 1998 the quality-adjusted price of laptops declined by an average of 40% per year. Other studies have found similar rates of decline (Berndt & Rappaport 2001).

The Bureau of Economic Analysis (BEA) introduced hedonic methods in the NIPAs for computer and peripheral equipment in December 1985 covering the period 1972 to 1984 (Moulton 2001: 4). Subsequently, the BEA introduced hedonic indexes for memory chips and semiconductors in January 1996 (Moulton 2001:5). Hedonic methods for computers were introduced later by the Bureau of Labour Statistics (BLS) to calculate consumer price inflation (CPI) in 1998 (Moulton 2001:7). Significantly, the BEA expanded its definition of capital, so that software expenditure was classified as fixed investment in 1999 (Moulton 2001:5).

Cole et al. (1986) summarised IBM's research into the application of hedonic methods to computer processors and peripheral equipment. They point out that the market for computers is characterised by disequilibrium, because of rapid technological change and the introduction of new products. This characteristic is evident from the observation that "two sets of prices coexist for products possessing the same characteristics – one price for the products based on the old technology and one for the products based on the new" (Cole et al. 1986:43).

The study concludes that the so-called "matched model" approach, which is the standard approach used in the NIPAs, understates price movements for computers. A further problem arises in the construction of a price index for computers because products that exist in the current period may not have existed in the base period. In the matched-model approach only products that existed in both periods are used in the index and those that exist currently are ignored. Because product turnover is rapid, price index numbers using this method are biased (Cole et al. 1986:48-50.)

However, these methods have been criticised, particularly when applied to computers. McCarthy (1997) argues that a distinction should be drawn between the potential output and actual input of computers, particularly personal computers. McCarthy (1997:3) captures the essence of the matter when he argues that computers are different from other types of capital insofar as computers have many built-in redundant features that most users will never use.

McCarthy (1997:6-7) raises two additional significant concerns – increasing complexity and quality improvement in software. The increasing size and complexity of operating systems and software results in growing inefficiencies between the hardware and the software. The growing complexity of and addition of largely unused features to desktop software packages (software which is also referred to as "bloatware") is captured by the quip: "What Intel giveth, Microsoft taketh away." Improvements in software programming have not kept pace with the rapid improvements in hardware quality, as measured by hedonic methods. The effect is that the joint improvement of software and hardware is lower than that of hardware alone as software developments continue to lag.

Hedonic methods are used in only a few European countries. Ahnert and Kenny (2004) provide an overview of European price statistics and the role of hedonics. Significantly, only Germany and the UK make hedonic quality adjustments for personal computers in their consumer price inflation calculations (Ahnert & Kenny 2004:27-28). The use of hedonic methods is therefore largely confined to the USA.

3.11. Software, quality changes and measurement

Generally, computer hedonic techniques focus on computer hardware and omit the analysis of computer software characteristics and quality change. Anselmo and Ledgard (2003) discuss productivity measurement in the software industry and contend that there are no acceptable productivity benchmarks for software. They propose that three yardsticks, functionality, complexity and quality, should form the basis of software productivity measurement (Anselmo & Ledgard 2003:125).

The authors maintain that there is a perception that programming standards are low and that the software is bug-ridden. Significantly, Anselmo and Ledgard (2003:121) find that software productivity is declining faster compared to other industries: "The semiconductor industry had the most productivity growth (86%) from 1990 to 1995. In that same period, productivity for the software industry decreased by 10%, indeed, the worst decline of all industries surveyed."

The overall functionality of the ICT industry cannot be divorced from the software component because hardware and software are complements. A productivity decline in the one industry cannot be fully compensated by productivity improvements in the other and will thus lower the overall productivity in the ICT industry. Chapter 6 will discuss the interaction of hardware and software and its effect on the combined productivity of the ICT industry.

3.12. Conclusion

This chapter showed that index numbers problems are a major challenge for the measurement of economic variables, but particularly for computerisation and the ICT industry. Krugman (1999:25) remarked that "anyone who has seen how economic statistics are constructed knows that they are really a subgenre of science fiction … actual estimates of economic growth are based on a good deal of fudging: on 'imputations' and 'approximations'".

Index numbers are widely used to measure economic variables in the USA and other countries' national accounts. Many index numbers are biased and therefore unsuitable for accurate price and quality measurements. Because computer hardware undergoes rapid quality improvements, it is essential that computer prices be adjusted to capture these improvements more accurately. Indeed, quality change poses the most challenging problem for the construction of price indexes.

Hedonic methods are the best methods available to estimate quality adjustments. However, they are not without problems, as explained above. These issues will be analysed more fully in chapter 6.

4. CHAPTER 4: PRODUCTIVITY AND COMPUTERISATION IN THE NATIONAL INCOME AND PRODUCT ACCOUNTS

4.1. Overview

The previous chapters provided the theoretical and methodological background to productivity measurement. This chapter examines the national accounting side of productivity, that is, how productivity and computerisation are actually incorporated into the USA national income and product accounts (NIPAs). The manner in which computerisation is actually accounted for in the NIPAs and the productivity performance of the USA are then discussed. The most recent multifactor productivity data (and the dissertation's cut-off point) from 1948 to 2002 are dealt with.

According to the OECD manual (2001:18), "the production theoretical approach to productivity measurement offers a consistent and well-founded approach that integrates the theory of the firm, index number theory and national accounts". The emphasis in this chapter is on productivity and related statistics in the US national accounts.

4.2. Revisions of the NIPAs and productivity measures

The productivity measures are subject to frequent revisions, which introduces an element of uncertainty, because productivity analyses can be based on outdated data. According to the BLS (2007c), quarterly labour productivity and costs are revised two to three times after the initial release. In addition there are three-year, five-year and variable time period revisions to the source data.

One recent important methodological change (as distinct from data recalculations as new information becomes available) was the switch from the 1987 Standard Industrial Classification (SIC) measure to the 1997 North American Industry Classification System (NAICS). (The codes are numerical classifications of industries used by many government statistical agencies.) The two systems are incompatible for the purposes of MFP measurement. This implies that MFP measures up to 2002 cannot be compared to the latest MFP data, which are based on the NAICS system starting in 2003, but revised back to 1987. MFP measures based on the SIC system will not be updated (BLS News 2005:1). MFP measures based on the old SIC system run from 1948 to 2002, whereas MFP based on the newer NAICS system runs from 1987 (to 2005 at the time of writing) (BLS News 2006a:1). This study will therefore deal with the period from 1946 to 2002, because this period is adequate to discuss the productivity paradox and captures a sufficient time span of the productivity revival (since 1995).

The BEA has made two significant recent revisions to the NIPAs, namely the "Comprehensive revision of the national income and product accounts" in 1999 and 2003. In 1999 three papers (1) "Measuring the New Economy", by Landefeld and Fraumeni; (2) "Recognition of business and government expenditures for software as investment: methodology and quantitative impacts, 1959-98" by Parker and Grimm; and (3) "Measurement of banking services in the U.S. national income and product accounts: recent changes and outstanding issues" by Moulton, played a critical role in the revisions. All these papers refer to the productivity issues already discussed. The 2003 revisions did not have a productivity focus.

4.3. Productivity definitions in the US and other OECD national accounts

Generally, productivity is the ratio between real output and real inputs used to produce that output. According to the OECD manual (2001:11) it is "commonly defined as a ratio of a volume measure of output to a volume measure of input use." Hence, productivity is the ratio of some measure of output per unit of input which relates the outputs of production to the inputs used to create them (Dean et al. 1995:30).

It measures the economic efficiency of production, revealing how effectively inputs are converted into output, thus enabling more goods and services to be produced without requiring an increase in labour time (BLS 2004). In terms of the actual measurement of output and inputs, Schreyer and Pilat (2001:146) define productivity as "the ratio of a quantity index of output to a quantity index of inputs". Suffice it to say that the actual measurement of output and inputs depend on the index numbers actually capturing what the theory requires.

Output and input are expressed as real variables, that is, at constant prices based on a particular year. Output can be expressed as either *gross output* or *value-added* output (Schreyer and Pilat 2001:128-136). Output is measured by the total goods and services produced; and the inputs by the physical and human resources used in the production process. Various inputs can be used: labour, capital, or labour and capital combined, or intermediate inputs such as energy, materials and services. There are several advantages and disadvantages to the different approaches. Value added is generally preferred because it avoids double counting.

Productivity measurement relates to a specific level of "an establishment, a firm, an industry, a sector or an entire economy" (Schreyer & Pilat 2001:129).

4.4. The Cobb-Douglas function and the NIPAs

The equation

$$LP^* = Q^* - L^* = (1-\beta)(K^* - L^*) + A^*$$

(equation (4) in chapter 2) is the core equation used in the NIPAs. It can be refined by further disaggregating the variables, as discussed in chapter 5.

Productivity is not a single concept, but a family of concepts (Fabricant 1969:116). However, there are two main productivity measures: single factor productivity measures and total factor productivity (TFP), or multifactor productivity (MFP). Single factor productivity measures are labour productivity (LP) and capital productivity. Multifactor productivity measures are in the form of capital-labour MFP; or of capital-labour-energy-materials MFP, or KLEMS MFP. In the KLEMS MFP measure, capital (K) and labour (L) are the main inputs, and energy (E), materials (M) and purchased business services (S) the intermediate inputs (OECD 2001:12-13). The KLEMS method is appropriate for industry level analysis.

The terms "TFP" and "MFP" are often used interchangeably. Since the USA statistical agencies use the term "multifactor productivity", it will be adopted here as well.

Although this study focuses mainly on labour productivity and multifactor productivity at aggregate level, industry and firm level productivity are also discussed (chapter 5). KLEMS MFP is therefore included, because it includes intermediate inputs. The various methods can be interpreted in a different way with diverse purposes, advantages and limitations. The OECD Manual (2001:14-18) discusses these fully.

Timmer (2001) explores the KLEMS approach and provides an overview of sources and methods. We give a brief overview here.

Table 4.1 the principal productivity measures.

Following on **table 4.1**, labour productivity (based on gross output or value added) is defined as

$$LP = \frac{\text{Quantity index of gross output or value added}}{\text{Quantity index of labour input}} \qquad (5.1)$$

Similarly, capital-labour MFP based on value added is defined as:

$$MFP = \frac{\text{Quantity index of value added}}{\text{Quantity index of combined labour and capital input}} \qquad (5.2)$$

The denominator, the quantity index of combined labour and capital input, is equal to a quantity index of labour and capital, where each factor is weighted with its current-price share in total value added.

Table 4.1. Main productivity measures				
	Single factor productivity measures		**Multifactor productivity measures**	
	Labour input	Capital input	Capital and labour inputs	Capital, labour, energy, materials and services inputs
Gross output	Labour productivity based on gross output	Capital productivity based on gross output	Capital-labour MFP based on gross output	KLEMS multifactor productivity
Value added	Labour productivity based on value added	Capital productivity based on value added	Capital-labour MFP based on value added	_
Source: OECD Manual (2001:13, table 1)				

The KLEMS multifactor productivity is defined as

$$KLEMS\ MFP = \frac{Quantity\ index\ of\ gross\ output}{Quantity\ index\ of\ combined\ inputs} \qquad (5.3)$$

The denominator, the quantity index of combined input, is equal to a quantity index of labour, capital, energy, materials and services, where each factor is weighted with its current-price share in total value added.

4.5. Labour productivity

Labour productivity (LP) is the ratio of the output of goods and services to the single input, labour, measured in labour hours, devoted to the production of that output (BLS 2004). In short, labour productivity, or output per hour of all persons, is the standard commonly-used measure and is generally the appropriate measure to assess the economy's ability to increase potential national income (BLS 2004). In the US business sector, labour costs comprise about 60% of the value of all output produced (BLS 2004).

Labour output can be expressed as output per worker or output per hour. Importantly, however, "labour productivity reflects the influence of all factors that affect productivity, including capital accumulation, technical change, and the organisation of production. While the intensity of labour effort is obviously a factor that does affect labour productivity, it is generally significantly less important than the amount of capital a worker has to work with or the level of production technology" (CSLS 1998:7).

4.6. Multifactor productivity

Multifactor productivity (MFP) is the ratio between real output of goods and services and the combined contribution of all inputs, but mainly of labour and capital. In essence, MFP measures a combination of changes in efficiency in the use of factor inputs and changes in technology (Collins & Bosworth 2003:114). It is also a useful tool to gauge the economy's productivity capacity of potential output which, in turn, has a direct bearing on growth and inflation (OECD Manual 2001:12).

MFP is appropriate for the assessment of the economy's efficiency in its use of capital and labour combined in the production process (CSLS 1998:8).

4.7. Unit labour costs

Unit labour cost (ULC) also features in productivity analysis and is an indicator of inflationary pressures on producers (BLS News 2006b:10). The BLS defines unit labour cost as the ratio of total labour compensation to real output, or equivalently, as the ratio of hourly compensation to productivity. Therefore

$$ULC = \frac{\dfrac{total\ labour\ compensation}{hours}}{\dfrac{output}{hours}} \qquad (5.4)$$

From the above equation we see that generally when hourly compensation rises, ULC rises as well; but when productivity rises, ULC falls. If both numerator and denominator change by the same percentage, ULC will be unchanged.

4.8. LP and MFP: general issues

The term "productivity" used in the popular media usually refers to LP (output per hour), not MFP or TFP. According to the BLS "Output per hour in the nonfarm business sector is the productivity statistic most often cited by the press." (BLS 2004).

In practice, measurement of the numerator and the denominator is subject to error. Errors in the indexes could produce large errors in the productivity ratio but could also cancel out (Fabricant 1969:16). An understanding of index numbers is therefore essential for the analysis of the productivity paradox. The use of index numbers was covered in chapter 3 (see Allen 1975; Diewert 1987; Oliner & Wascher 1995).

Labour and multifactor productivity are two different measures of "overall" productivity. The best or most appropriate measure depends on the circumstances as well as the intended use of the results. As argued in the Introduction, labour productivity is closely associated with a country's standard of living. Labour productivity also depends on capital deepening and is therefore subject to additional measurement error.

TFP clarifies technical change, but TFP can be criticised on theoretical grounds. Sargent and Rodriquez (2000:11-13) argue that the choice depends on the following:

(1) the time period of interest – TFP is a better long-run guide, whereas labour productivity is more appropriate for periods of less than a decade;

(2) the integrity of the capital stock data – there are biases in capital stock estimations for TFP and cross-country comparisons are subject to differing methods between statistical agencies; and

(3) the underlying economic growth model - whether neoclassical or new growth theory.

MFP growth is usually lower than LP growth. This is so because the capital stock grows at a faster rate than employment (labour), resulting in a rising capital-labour ratio. The growth rate of capital and labour combined (MFP) is thus higher than the growth rate for labour alone (LP); and the larger denominator of labour and capital combined compared to labour alone (holding the numerator constant), results in lower MFP growth compared to LP growth (see equations (5.1) & (5.2) above).

4.9. Factor income shares in the NIPAs

Factor inputs are usually weighted according to their income shares. Factor income share are discussed in chapter 2. This chapter shows how the shares of capital and labour in income are actually calculated from the NIPAs.

The share of income is derived as follows **(table 4.2)**:

Table 4.2: National income by type of income: labour and profit shares in 2001 (US$ billions)				
				% share in total income
Labour	Compensation of employees		5 874.9	72%
Profits	Proprietors' income	727.9		
	Rental income of persons	137.9		
	Corporate profits	731.6		
	Net interest	649.8		
	Total profits		2 247.2	28%
National income			8 122.1	100%
Source: BEA (2002:D-6, table 1.14); based on Hall & Taylor (1997:38, table 2.5)				

The actual weights change from year to year. For example, in Hall and Taylor (1997:38), the weights for 1996 are 73% for labour and 27% for capital, a marginal difference.

4.10. Sectors and subsectors in productivity measurement

Productivity measures are available for major sectors as well as subsectors of the US economy. **Table 4.3** is useful to determine the differences between the different sectors for which LP and MFP data are available.

The two sectors for which MFP is calculated are the "Private business sector" and the "Private nonfarm business sector" (BLS 2007b).

The three main sectors for which LP is calculated are the "Private business sector", the "Private nonfarm business sector" and the manufacturing sector. The manufacturing sector in turn is subdivided in the "Durable goods manufacturing" sector and the "Nondurable goods manufacturing" sector.

Table 4.3: Derivation of the private business sector
Gross domestic product (GDP)
Less: General government
Equals: Total private economy
Less: Output of household workers, nonprofit institutions, gross housing product of owner-occupied dwellings and the rental value of nonprofit institutional real estate
Equals: Business sector
Less: Government enterprises
Equals: Private business sector
Less: The farm sector
Equals: Private nonfarm business sector
Source: Notes to BLS (1997)

Multifactor productivity measures *exclude* government enterprises as shown in **table 4.3**. In particular, the private business sector "excludes the output of general government, government enterprises, non-profit institutions, the rental value of owner-occupied real estate, and the output of paid employees of private households". The private nonfarm business subsector "excludes farms, but includes agricultural services" in addition to the above exclusions of the private business sector. According to the BLS (2003), the private business sector accounts for 76% of GDP in the USA. This sector essentially measures the for-profit sector and is the broadest sector for which MFP is measured (BLS 2007b).

As mentioned above, according to the BLS: "Output per hour in the nonfarm business sector is the productivity statistic most often cited by the press" (BLS 2004).

4.11. Data sources and procedures used in the US productivity measurements

4.11.1. The statistical agencies: BLS and the BEA

The productivity calculations are based on indexes provided by two US government agencies: the US Bureau of Labour Statistics (BLS) of the US Department of Labour and the Bureau of Economic Analysis (BEA) of the US Department of Commerce. The BLS regularly publishes productivity statistics: labour productivity is published every quarter; but MFP less regularly, since it is based on data not available on a quarterly basis. The BEA publishes the monthly *Survey of Current Business*, an important source of US productivity and other data and general economic analysis. All of the data discussed in this chapter are available online on the two agencies' respective websites.

The BLS and BEA publications can be confusing because the bureaus' nomenclature does not always tally with the theoretical or academic expositions. An overview is therefore included here with comments on conventions and methods, data sources and procedures.

Productivity calculations are based on indexes provided mainly by the US BLS and the BEA as mentioned. Output data are provided by the BEA and adjusted by the BLS to remove the output of government enterprises. Capital measures are provided by the BEA and the US Department of Agriculture.

Industry productivity measures published by the BLS are only available at the aggregate national level: industry productivity statistics are not broken down for separate regions, states and cities because data sources do not provide the required information.

The BLS publishes productivity statistics at different time intervals. The series on labour productivity measures are published quarterly under the general heading "Productivity and Costs". These data series are published promptly: for example, the data release for the 2006 fourth quarter and annual averages (revised) was available on 6 March 2007. Multifactor productivity series are published annually under the general heading "Multifactor Productivity Trends". These series are published after some delay, for example, the annual release for 2005 was only published on 23 March 2007.

It is useful to know that LP and MFP measures are available as follows (**table 4.4**):

Table 4.4: Availability of productivity measures of major sectors and subsectors		
Productivity measure	Input(s)	Index available
Labour productivity		
Business	Labour	Quarterly
Nonfarm business	Labour	Quarterly
Nonfinancial corporations	Labour	Quarterly
Manufacturing, total	Labour	Quarterly
Durable manufacturing	Labour	Quarterly
Nondurable manufacturing	Labour	Quarterly
Multifactor productivity		
Private business	Labour, capital	Annually
Private nonfarm business	Labour, capital	Annually
KLEMS multifactor productivity		
Manufacturing and 20 2-digit SIC manufacturing industries services	Labour, capital, energy, materials, services	Annually
Source: BLS (1997:89, table 1)		

4.11.2. The BLS and labour productivity

Labour productivity, which the BLS refers to as “output of all persons”, is published quarterly. Labour productivity is published for the following categories on a quarterly basis: “business”; “nonfarm business” – a subsector of the business category; “nonfinancial corporations” – a subsector of the nonfarm business category; “manufacturing, total” – a subsector of the nonfinancial corporations category; and lastly the “durable manufacturing” and “nondurable manufacturing” subsectors – subsectors of the total manufacturing category. Labour productivity measures *include* government enterprises (BLS 2003).

Labour, which is the only input, is an “index of the hours at work of all persons including employees, proprietors, and unpaid family workers classified by education, work experience, and gender.” (BLS 2005: 15, footnote 4).

4.11.3. The BLS and multifactor productivity

Multifactor productivity is published annually, because it is based on data not available on a quarterly basis. Multifactor productivity measurements are published as indexes that measure the value-added output per combined unit of labour and capital inputs. Two sectors are covered, namely the “private business” sector and the “private nonfarm business” subsector. The latter is often referred to in the literature as well as in this dissertation.

According to the BLS (BLS 2003), multifactor productivity relates real output to combined inputs, which are essential factors in the production of output. The contributions made by the specific factors of production are not measured. The joint influences of these essential factors are measured, thus capturing the effects of technological change, efficiency enhancements, economies of scale, resource reallocation between industrial sectors and other factors impacting on economic growth.

4.11.4. The BLS and KLEMS

A second measure of multifactor productivity is also available, the so-called “KLEMS multifactor productivity” measure. KLEMS multifactor productivity indexes measure sector output per combined units of the capital, labour, energy, materials and purchased business services inputs. The sectors measured are for aggregate manufacturing; and for 20 two-digit Standard Industrial Classification (SIC) manufacturing industries. It is also published annually and also *excludes* government enterprises (BLS [S.a.]).

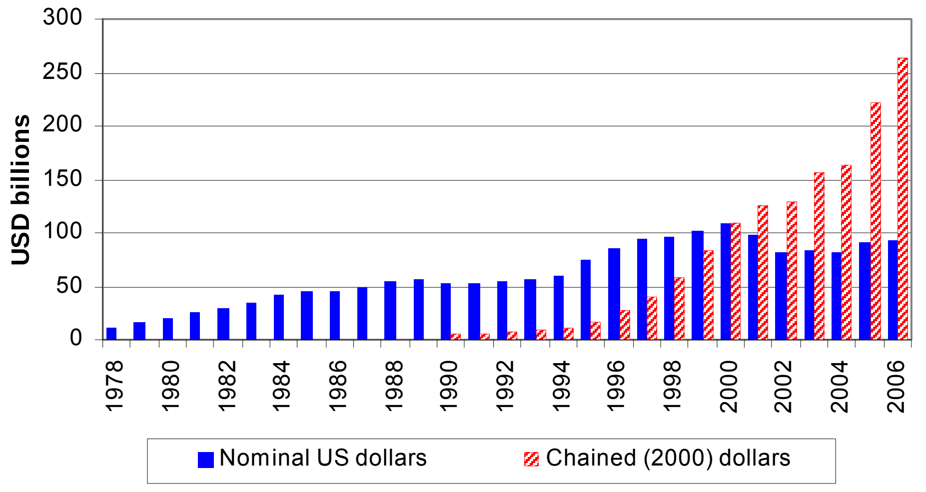
4.12. Computers in the NIPAs

Computers are listed in four sections in the national income and product accounts (NIPA) (Haimowitz 1998; Landefeld & Fraumeni 2001:28). The sections are personal consumption expenditures, business fixed investment, government and net exports. Computers are not defined in exactly the same way under the four components (Haimowitz 1998:29).

Two of these sections are of interest for the analysis of computers and the Solow paradox. The first, “Final sales of computers”, in nominal and in chained dollars, is published in the national accounts and shown graphically in **figure 4.1**. The series starts in 1978 as shown. Chained indexes, which link indexes spanning shorter periods together to form indexes spanning longer periods, were examined in chapter 3. The BEA’s table 1.2.5. (line 17), entitled “Gross domestic product by major type of product" and table 1.2.6. (line 19), entitled "Real gross domestic product by major type of product, chained dollars" are shown.

The second measurement is "Private fixed investment in computers, software, and communication" from the BEA's table 5.5.5. (line 4), entitled "Private fixed investment in equipment and software by type" and is shown in **figure 4.2**. The series starts in 1959, but data from 1973 are shown graphically. The series is further disaggregated into three subcomponents: computers and peripheral equipment, software, and communication equipment. The communication equipment data series starts in 1929, whereas the other two series start in 1959.

Figure 4.1: Final sales of computers: nominal and chained dollars

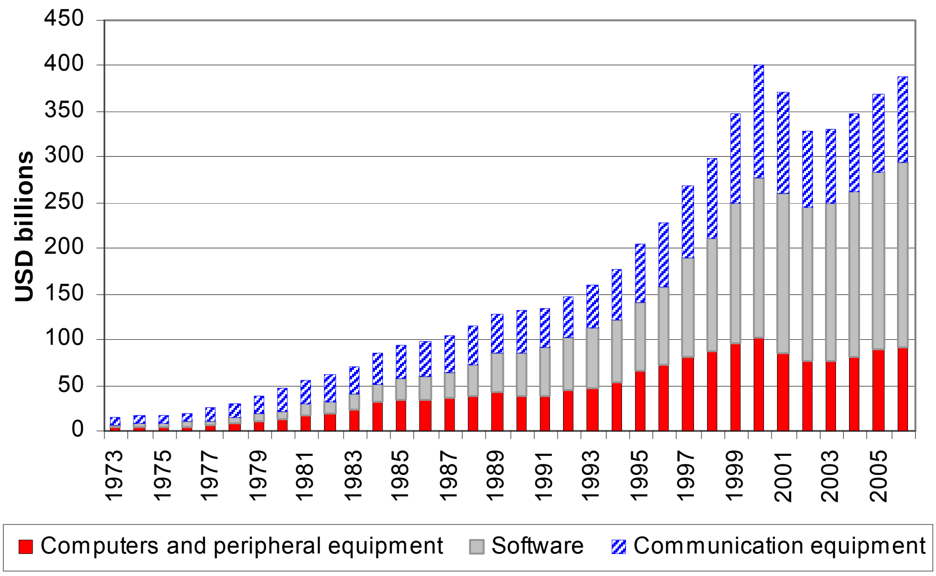


Source: BEA NIPA (2007: tables 1.2.5. & 1.2.6.**)**

4.13. <u>ICT and capital flow tables</u>

In its publication, the *Survey of Current Business* (SCB), the BEA presents capital flow tables from time to time, which facilitate analyses that "are not possible using only the I-O table" and are supplementary to the I-O table (Meade et al. 2003:18). The I-O tables refer to input-output accounts developed by Leontief (Meade et al. 2003:18).

Figure 4.2: Private fixed investment in computers, software and communication



Source: BEA NIPA (2007: table 5.5.5); Note: Earlier data are available but not shown here.

Capital flow tables (CFT) have been published (or are available on the BEA's website) for selected years: 1963, 1967, 1972, 1977, 1982, 1992 and 1997. (The publication of the capital flow tables are somewhat delayed; the 1963 table was published in 1971; the 1967 table in 1975; the 1972 table in 1980; the 1982 table in 1985; the 1992 table in 1998; and the 1997 table in 2003.)

The capital flow table "shows the structure of flows on new capital goods and services for each industry" (Meade et al. 2003:18). In particular, the improvements made to the 1997 capital flow table provided more information on the services industries and the information sector, a large market for IT capital; and software investment (Meade et al. 2003:18). CFTs are consistent with the NIPAs: NIPA categories are simply aggregates of the more detailed I-O commodities (Meade et al. 2003:19). For example, **table 4.5** shows the NIPA tables with line numbers, I-O commodity for ICT at producers' and purchasers' prices[1].

[1] Purchasers' prices = Producers' prices + Transportation costs + Wholesale and retail margins.

Table 4.5: I-O commodity composition for computers (US$ millions)			
NIPA line	I-O commodity	Producers’ prices	Purchasers’ prices
4	Computers and peripheral equipment (total)	$63,281	$81,850
6	Communication equipment (total)	$72,908	$80,107
Source: Meade et al. (2003:19, table A)			

CFTs are useful for the analysis of intensity of ICT usage by all industries, where intensity of usage is measured by ICT share in total equipment and software investment. Of the top 20 most intensive ICT users, only one industry is in the manufacturing sector, namely computer and peripheral equipment manufacturing; whereas of the top 10, five are in the information sector and four in the financial activities sector (Meade et al. 2003:21 & table D).

Based on **table 4.6** and the I-O industry codes, the first two digits 51 of the I-O codes denote the information sector, and 52 and 53 the financial activities sector.

Table 4.6 shows the top 10 users and ICT shares.

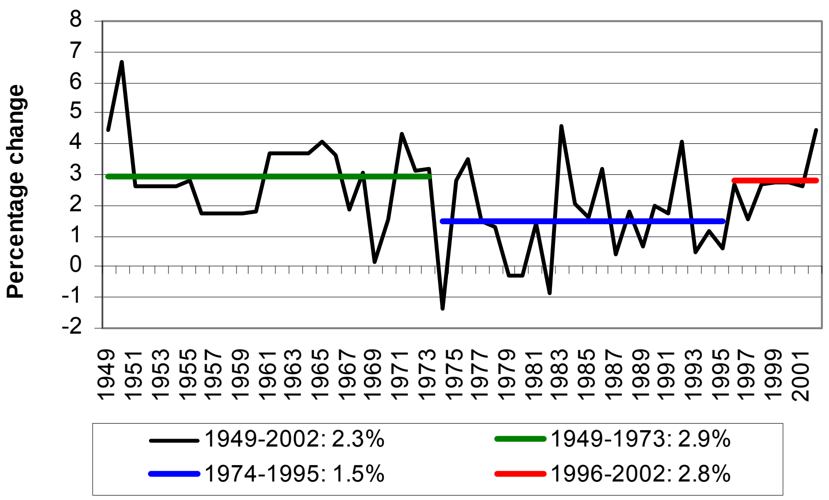
However, for the first time, the 1997 CFTs are based on NAICS, not SIC (see **section 4.2**), thus limiting comparability with earlier tables (Meade et al. 2003:25).

Table 4.6: Top 10 ICT-intensive industries ranked by 1997 ICT share in total equipment and software investment		
I-O code	Industry	ICT share
5132*	Cable networks and program distribution	91%
5415	Computers systems design and related services	89%
5112*	Software publishers	88%
5250**	Funds, trusts and other financial vehicles	88%
5142*	Data processing services	87%
5330**	Lessors of nonfinancial intangible assets	84%
5133*	Telecommunications	82%
52A0**	Monetary authorities, credit intermediation and related	80%
5131*	Radio and television broadcasting	77%
5230**	Securities, commodity contracts, investments	76%
Source: Meade et al. (2003: 21, table D); Notes: * = information sector; ** = financial sector.		

4.14. Productivity growth trends in the USA from 1948 to 2002

Figure 4.3 shows labour productivity growth trends from 1948 to 2002. The average LP growth over the period is 2.3%.

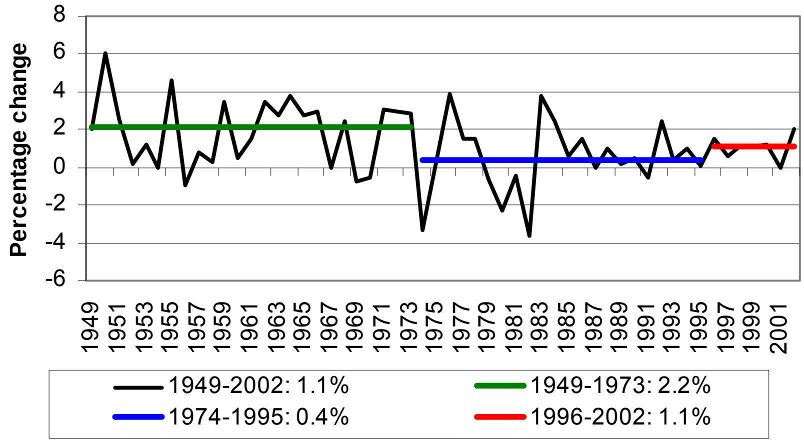
Figure 4.3: Labour productivity growth trends, private nonfarm business sector (1948 to 2002) (% change)



Source: BLS News (2005:14, tables 2 and 4)

Figure 4.4 shows MFP growth trends from 1949 to 2002. MFP growth averaged 1.1% over the period.

Figure 4.4: Multifactor productivity growth trends, private nonfarm business sector (1948 to 2002) (% change)



Source: BLS News (2005:12, table 2; 14, table 4)

A summary in table format of the productivity growth figures is also reproduced here to illustrate the growth trends. **Table 4.7** refers to the private nonfarm business and excludes government enterprises.

Table 4.7: Productivity growth trends, private nonfarm business (1948 to 2002)							
	1948 - 2002	1948 - 1973	1973 - 1990	1990 - 1995	1995 - 2000	2000 - 2002	2001 - 2002
1 Output per hour of all persons	2.2	2.9	1.4	1.6	2.5	3.6	4.5
2 Contribution of capacity intensity	0.9	0.8	0.8	0.5	1.1	1.8	1.7
2.1 Contribution of information processing equipment and software	0.3	0.1	0.4	0.4	0.9	0.9	0.8
2.2 Contribution of all other capital services	0.5	0.7	0.4	0.0	0.2	0.9	0.9
3 Contribution of labour composition	0.2	0.2	0.2	0.4	0.3	0.7	0.8
4 Multifactor productivity	1.2	1.9	0.4	0.7	1.1	1.0	2.0
4.1 Contribution of R&D to multifactor productivity	0.2	0.2	0.2	0.2	0.2	0.3	0.3
Source: BLS News (2005:6, table B)							

The additions may not add up exactly because of independent rounding. Line 1 is simply labour productivity (LP). Line 2, the contribution of capital intensity, refers to the growth rate in capital services per hour multiplied by capital's share of current dollar costs. Line 2.1, the contribution of information processing equipment and software, refers to the growth rate of information processing equipment and software multiplied by its share of total costs. Line 3, the contribution of labour composition, refers to the growth rate of labour composition multiplied by labour's share of current dollar costs and labour composition refers to the growth rate of labour input less the growth rate of the hours of all persons. Line 4, Multifactor productivity, refers to the output per unit of combined labour and capital inputs (BLS News 2005:6).

4.15. Conclusion

The aim of this chapter was to reconcile the gap between theoretical and academic studies with the productivity statistics as calculated by the official US government agencies. The statistical agencies respond to the criticisms and comments by academic researchers on improving the productivity statistics.

5. CHAPTER 5: ECONOMICS OF INFORMATION TECHNOLOGY

5.1. Overview

The chapter deals with the following: a brief history of computing; a short discussion on three interpretations of IT value; the relationship between computers and economic growth; the distinction between computer-using and computer-manufacturing industries; productivity at various economic levels (aggregate, industry and firm levels); computerisation and the services sector; productivity, technical change and the residual; the computer prices and investment; and the internet and the new economy.

The starting point of this chapter is the methodology adopted and many of the issues raised in Sichel's seminal book, *The computer revolution: an economic perspective*, published in 1997, because it aims to provide "an economic perspective on the principal issues." (Sichel 1997a:7). Sichel's book is based on the economic theory of computerisation developed in an earlier paper by Oliner and Sichel (1994), entitled *Computers and output growth revisited: how big is the puzzle?* In reviewing the book, Solow (1998:120), remarked that "He tells the best story you are likely to hear" regarding the productivity paradox. Madrick (1998:53) believes that Sichel "sets a standard for rational discussion that has largely been missing to date".

For conceptual clarification, it is imperative at the outset to nail down what computer productivity *is not*, to eliminate confusion over the scope of the economics of computerisation. Many discussions on computers focus on their perceived value or usefulness to consumers and business, as well as ubiquity, which is indicative of computer output only rather than productivity as a ratio of output and input. These discussions do not consider the relevant productivity puzzle: namely the relationship (or ratio) between computer output and computer input.

5.2. Highlights of computing history

Information technology and processing have a long history and preceded the invention of the modern computer. Typewriters, telegraphs, telephones and office calculating machines have been used by businesses for an extended period (Sichel 1997a:12). The purpose of this brief overview is to stress the continuity of current and past developments in computing, where computing is understood in a wider sense.

It is not necessary to discuss the history of the computer and the microchip in detail here. For a half-century history of computing see the Institute of Electrical and Electronic Engineers' *Timeline of computing history* (IEEE 1996). The publication marks the 50th anniversary of the invention of modern computing. However, the IEEE dates the advent of computing generally at about 4 000 to

12 000 BC with the Sumerian's use of the clay tablet to capture commercial transactions, followed by the invention of the abacus in Babylonia in 3 000 BC.

More recently, the vacuum tube was invented in 1904 (IEEE 1996). Modern information technology, however, commences with the invention of the transistor at the Bell Labs in 1947 (Jorgenson 2001:2). A transistor is a type of semiconductor which is an electronic component made from semiconductor materials such as silicone or germanium (Microsoft computer dictionary 2002:"transistor"). The three inventors of the transistor won the Noble Prize for Physics in 1956.

The integrated circuit, which consists of many interconnected transistors, resistors and other circuit elements placed on a single chip (Microsoft computer dictionary 2002:"integrated circuit"), was coinvented in 1958 and 1959. In 2000, one of the inventors won the Nobel Prize for Physics for the integrated circuit.

In 1956 Gordon Moore made the prescient observation that chip capacity (the number of transistors on a computer chip) rose exponentially, doubling every year. A decade later he predicted it would double every two years. Subsequently, the actual capacity doubling was found to take 18 months (Microsoft … 2002:"Moore's law"). This prediction, the actual doubling of capacity every 18 months, became known as Moore's law. This law is often referred to in the context of the rapid progress in computer technology.

The first electronic computer, the ENIAC, containing 18 000 vacuum tubes and programmed with thousands of switches set by hand, was developed during World War II. Its successor the UNIVAC I, using stored programs rather than switches, was built for the US government for the 1950 census. The first commercial UNIVAC machine was purchased in 1954. Before 1965, most of the computers sold were mainframes, but subsequently sales of minicomputers and microcomputers rose dramatically (Gordon 1989:79-81).

The first microchip, a microprocessor with the capacity to execute software programs or logic chip, was developed by Intel Corporation in 1971. The first "computer on a chip" made in 1971 had 2 300 transistors compared to the 42 million transistors on the Pentium 4 made in 2000 - implying an exponential growth rate of 34% per year over the three decades (Jorgenson 2001:3). In 1971, the first e-mail was sent on a network.

IBM launched the first personal computer (PC) in 1981. The PC incorporated the Intel 8086-8088 microprocessor and the Microsoft MS-DOS operating system, cementing a business relationship still in operation today. With the release of the Microsoft Windows operating system in 1985, the Wintel (Window-Intel) ties were further strengthened (Jorgenson 2001:5).

The invention of the global internet dates from 1983 with the creation of TCP/IP. The acronym stands for *Transmission control protocol/internet protocol*, which is a set of rules or standards for data transmission over interconnected networks (such as the internet) developed by the US Department of Defense (Microsoft computer dictionary 2002:"TCP/IP").

The first mention of the word "software" was in 1962 in relation to the development of synthesised music. In 1968 (the second mention) the term "software engineering" was introduced at a NATO Science Committee conference to address the "software crisis".

It is evident that the measurement problems associated with computers emerged during the early days of computing history, that is in the 1950s.

5.3. Moore's law and semiconductor prices

Moore's Law, outlined above, has an enormous influence on quality-adjusted computer prices and hence the computer productivity paradox. Jorgenson (2001:3) opines that as new generations of these devices improve in quality and speed:

> The economics of semiconductors begins with the closely related observation that semiconductors have become cheaper at a truly staggering rate! … The behaviour of semiconductor prices is a severe test for the methods used in official price statistics. The challenge is to separate observed price changes between changes in semiconductor performance and changes in price that hold performance constant.

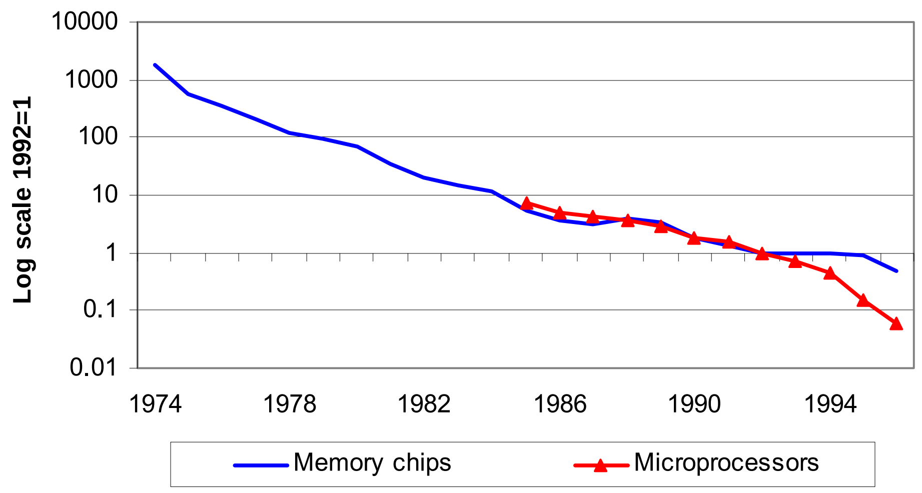
The previous chapter outlined index numbers for this very reason. The problem led to the eventual replacement of the matched-model method with the hedonic method for computer prices.

The rapidity of price declines is evident in **figure 5.1**, based on research conducted by Grimm (1998). His research showed that the price index of memory chips fell by an annual average of 36.9% between 1975 and 1985 and by an annual average of 20.1% between 1985 and 1996 (Grimm 1998:8 & 12); and that the price index of microprocessors decreased by an annual average of 35.3% between 1985 and 1996 (Grimm 1998:8 & 23).

Moore's Law could be cited as a cause of productivity growth acceleration in microprocessors in 1995; however, it "predicts a constant rate of growth of capability, not an accelerating rate of growth" and the assumption is therefore problematic (Lewis 2004:90).

The impact of declining computer prices is further discussed below (**table 5.1**).

Figure 5.1: Falling prices of memory chips and microprocessors



Source: Grimm (1998:12, table 4); Grimm (1998:23, table 12)

5.4. <u>"Three faces of IT value"</u>

To fix ideas, Brynjolfsson and Hitt (1994:263-4) note that three separate questions, based on three logically distinct concepts, need to be asked in relation to IT value. The relevant questions are:

(1) whether investments in computers have increased productivity;

(2) whether investments in computers have improved business performance; and

(3) whether investments in computers have created value for consumers (this refers to the welfare effects of computers).

Brynjolfsson (1996:285-287) also provides the theoretical background to consumer welfare, including four basic approaches to consumer surplus. Brynjolfsson and Hitt's table, reproduced in **table 5.1**, shows the "three faces of IT value" and the framework within which each value should be examined.

Table 5.1: “Three faces of IT value”	
Issue	**Framework**
Productivity	Theory of production
Business performance	Theories of competitive strategy
Consumer value	Theory of the consumer
Source: Brynjolfsson & Hitt (1994:264)	

Brynjolfsson and Hitt (1994:274), in their firm-level study of 367 large firms over the period 1988 to 1992, concluded that IT increases productivity and the consumer surplus, but does not increase business profits. They found that there is no contradiction in these results and that they are consistent with economic theory.

Brynjolfsson (1996:281 & 297) estimated the contribution of IT to consumer welfare and found that IT investments “generate approximately three times their cost in value for consumers”, which amounted to between \$50 billion and \$70 billion in 1987, and which is growing steadily.

Sichel (1997a:30-32) also discusses the welfare effects of computers, under two headings: (1) net output, and (2) the consumer surplus. Net output will be further discussed in chapter 6, where the major explanations of the productivity paradox will be evaluated. This key issue revolves around whether gross or net output is the correct measure, the subject of a heated debate in the *Survey of Current Business* between Denison (1969; 1972) and Jorgenson and Griliches (1972). Briefly, because computers depreciate and become obsolete so quickly, the net measure of computer output (i.e. net of depreciation) greatly reduces the contribution of computers to output growth. According to Sichel (1997a:31), two-thirds of the gross rate of return to computers is accounted for by the costs of depreciation and obsolescence alone. The consumer surplus refers to the familiar idea that the consumer derives surplus satisfaction, utility, or extra benefits exceeding the actual price paid for a good or service. Sichel (1997a:31) argues that the consumer receives a bonus, the consumer surplus, as computer prices fall rapidly over time. The surplus, however, is difficult to measure and is not included in measurement of output growth (Sichel 1997:84). A graphic depiction of the consumer surplus is shown below (the shaded area P_1ABP_2 in **figure 5.4** on page 104 below).

This dissertation will deal mainly with computer productivity and the associated theory of production (i.e. the production function approach outlined in chapter 2).

5.5. Computers and economic growth

Jorgenson and Stiroh (1995:109) examined the impact of computers on economic growth and found that IT investment "generates substantial returns for the economic agents who undertake IT investments and restructure their activities in order to increase the role of IT". This is mainly because of falling IT prices and substitutions of IT capital and equipment for other types of capital and labour.

IT contributes to economic growth through two channels: firstly, by raising overall investment and hence capital deepening; and, secondly, by raising MFP. However, whereas the first channel has been accepted generally, the second is more controversial (Pilat, Lee & van Ark 2002:48). In this regard, Gordon (2000b) argued that MFP – technical progress – has been achieved primarily in the *production* of ICT goods and services.

This section is based on Sichel's important contribution *The computer revolution: an economic perspective* (1997a) as mentioned earlier, particularly pages 19 to 21 and 36 to 38. Generally, the contribution of computers to growth is a function of the quantity of computers that is in use and the average return earned by them (Sichel 1997a:15).

In the neoclassical framework, the contribution of computers to real output growth ($\dot{Y}_c$) can be calculated as the product of the share of total income generated by computers (s_c) and the growth rate of the stock of computer capital ($\dot{K}_c$), that is

$$\dot{Y}_c = s_c \dot{K}_c$$

The share of computer income (s_c) is calculated as follows (Sichel 1997a:19):

s_c = (nominal income flow) / (total income)

= [(gross rate of return) x (nominal stock of computers)] / (total income)

The income share of computers is related to the competitive rate of return of other investments. To calculate the gross rate of return on computers, the competitive rate of return earned on other investments is adjusted for depreciation, as follows:

(gross rate of return) = (competitive net return) + depreciation

$= r_{comp} + d$

The value of the nominal competitive net return to all nonresidential equipment and structures averaged 12% between 1970 and 1992; and the rate of depreciation of computers averaged 25% per annum over the same period. (These two calculations are based on the earlier paper by

Oliner & Sichel (1994:283-85)). Hence, adding these rates together gives the large gross rate of return of 37% for computers.

The rapid rate of computer depreciation requires a large gross return, net of depreciation. If computers did not earn such large returns, their owners would lose money after taking into account the rapid rate at which computers become obsolete (Sichel 1997a:20).

The nominal stock of computers and peripheral equipment amounted to US$95.9 billion in 1992. The nominal income flow was therefore about US$35.5 billion (US$95.9 billion x 0.37).

Nominal total income was US$4 494.4 billion in 1992; and US$35.5 billion as percentage of this total income amounted to 0.8% (i.e. s_c = 0.8%). Hence, assuming that computer hardware earned a competitive return, computers generated only 0.8% of total income in the whole economy in the US in 1992.

The next section looks at the above calculations in more detail.

5.6. Accounting for the contribution of computing services to output

Oliner and Sichel (1994:281) and Sichel (1997a:111-112) use the BLS (1983:33-34) methodology to include computers in the baseline production function approach and growth accounting framework to assess the contribution of computing equipment to output by separating out computing equipment from all other forms of capital. Sichel (1997a:79) argues that "hardware cannot be used in isolation … businesses are interested in the "computing services" flowing from their information technology, and … are the joint product of hardware, software and labour input."

Sichel therefore goes further by separating out two additional components that make up computing services generally, namely software and computer-services labour.

Based on Oliner and Sichel (1994:281, equation (3)), from equation (2) in chapter 2, yields

$$\ln Q = \ln A + \alpha \ln K + \beta \ln L$$

where K is capital, L is labour and A is technical progress.

When computing equipment K_C is separated out from total capital K, equation (2) becomes

$$\ln Q = \ln A + \alpha_C \ln K_C + \alpha_O \ln K_O + \beta \ln L \qquad (5)$$

where α_C is the share of computing capital in total income, $\alpha_C \ln K_C$ is the contribution of computer capital to growth and $\alpha_O \ln K_O$ is the contribution of noncomputer capital (i.e. all capital other than computers) to growth. (Equation (5) is based on Sichel (1997a:111), equation (4A-6)). The share of computer income α_C cannot be observed and the user cost of capital is used as a proxy (Oliner & Sichel 1994:282). Sichel (1997a:111-112) bases his calculations on this method as well.

When computing services are introduced fully into the calculations – that is, not only is the contribution of computer capital (hardware) separated from noncomputer capital, but the contributions of computer software ($\alpha_{CS} \ln K_{CS}$) and computer-services labour ($\beta_C \ln L_C$) are also incorporated – equation (5) can be extended as follows:

$$\begin{aligned} \ln Q &= [\alpha_C \ln K_C + \alpha_{CS} \ln K_{CS} + \beta_C \ln L_C] + \alpha_O \ln K_O \\ &+ (\beta \ln L - \beta_C \ln L_C) + \ln A \end{aligned} \qquad (6)$$

where $(\beta \ln L - \beta_C \ln L_C)$ is the term for total labour other than computer-services labour (Sichel 1997:111-112). The first three terms [in square brackets] describe the neoclassical contribution of computing services to output growth. These equations are all based on neoclassical assumptions (see Sichel 1997:18-21; 2002:16-17), which will be further explored in chapter 6.

In a later paper, Oliner and Sichel (2002b:16) extend the above analytical framework to include semiconductors. Whereas computer hardware, software and communications equipment are final goods and services, semiconductors are intermediate inputs.

We can thus observe that the contribution of IT to growth is measured from the input side rather than the output side (Sichel 1997a:91). This implies – the issue is taken up in chapter 6 – that the mismeasurement of *output* cannot affect the neoclassical calculation of IT's contribution to productivity growth. The contribution of IT to output is a function of the stock of computers and the return earned by IT.

The implication is that the mismeasurement of the contribution of computers to output could be captured by the MFP residual rather than computer capital and labour (as calculated by the above equations), thus understating computer productivity but at the same time overstating MFP. This is so because productivity changes must be captured somewhere. As Norsworthy (1984:327) notes: the growth accounting framework is a "filing system that is complete, in the sense that all phenomena that affect economic growth must do so through input factor quantities, relative factor intensities or total factor productivity growth, either simply or in combination."

Stiroh (2001e) also examines the economic impact of IT on growth and adopts an approach similar to that of Oliner and Sichel (1994) and Sichel (1997a). However, in contrast to the above approach, Stiroh points out that in the production function approach, IT is both an input and an output. IT is an *output* of firms and industries that produce IT goods and is thus part of *Y* in the national accounts. IT output can be separated from non-IT output. IT is also an *input* into the production process of other IT-using firms and industries which adds to the stock of productive capital of those industries and firms that uses IT. IT input can be separated from non-IT input

(Stiroh 2001e:5 & 13). According to Stiroh (2001e:5), IT investment goods include computer hardware, computer software and telecommunications equipment.

Higher production of IT goods should raise output. An improvement in the production of IT should raise MFP growth since it should be counted as technological change. However, investment in IT should raise the IT capital stock and thus add to IT input, but IT investment does not raise MFP or technological progress. Higher IT investment raises the amount of capital per worker, and hence capital deepening, which raises labour productivity (Stiroh 2001e:15-16.)

Taking the above into account, one can write

$$Y(Y_n, I_c, I_s, I_m) = A \cdot f(K_n, K_c, K_s, K_m, L)$$

where the subscript *n* denotes non-IT investment and input, the subscript *c* real computer hardware and capital services, the subscript *s* software investment and capital services and the subscript *m* telecommunications equipment investment and capital services (Stiroh 2001e:13). The above equation can be restated as a growth rate equation with the appropriate weights, which is a standard growth accounting equation (see Stiroh 2001e:13-14).

Jorgenson and Stiroh (2000b:142) adopt a similar methodology as Stiroh (2001e), but further separate out “computer and software consumption” and “services of consumers’ computers and software”. The results of such a growth accounting exercise are given in the **table 4.2**.

Table 5.2: Sources of GDP growth (annual average percentage growth rates)					
	Outputs				
	1948-2002	**1948-1973**	**1973-1989**	**1989-1995**	**1995-2002**
Gross Domestic Product	3.36	3.99	2.97	2.43	3.59
A. Contribution of IT	0.28	0.11	0.35	0.37	0.64
1. Computers	0.13	0.03	0.18	0.15	0.34
2. Software	0.07	0.02	0.08	0.15	0.19
3. Communication equipment	0.08	0.07	0.09	0.08	0.11
B. Contribution of non-IT	3.18	3.88	2.62	2.05	2.95
1. Contribution of non-IT Investment	0.69	1.05	0.44	0.21	0.41
2. Contribution of non-IT Consumption	2.49	2.82	2.18	1.85	2.54
	Inputs				
	1948-2002	**1948-1973**	**1973-1989**	**1989-1995**	**1995-2002**
Gross Domestic Income	2.79	2.99	2.68	2.17	2.88
A. Contribution of IT capital services	0.36	0.15	0.38	0.49	0.93
1. Computers	0.17	0.04	0.20	0.22	0.52
2. Software	0.08	0.02	0.07	0.16	0.23
3. Communication equipment	0.11	0.09	0.11	0.10	0.18
B. Contribution of non-IT Capital Services	1.39	1.79	1.15	0.71	1.07
C. Contribution of Labour Services	1.05	1.04	1.15	0.98	0.88
Total Factor Productivity	0.67	1.00	0.29	0.26	0.71
Note: Contribution of an output or input is the rate of growth multiplied by the average value share.					
Source: Jorgenson (2005: table 2.6)					

5.7. Computer-using and computer-producing industries

The literature distinguishes between industries that manufacture computers and those that use computers. The distinction between *production* and *use* of IT is important, because greater investment in IT can affect either labour productivity or MFP (or both).

Theoretically, IT contributes to economic growth, firstly, through higher overall investment and hence capital deepening, and, secondly, through MFP growth. Whereas there is consensus that IT investment has contributed to overall investment growth, it is more controversial whether IT has boosted MFP (Pilat et al. 2002:48), as was mentioned in **section 5.5**.

Similarly, Jorgenson (2001:26) states that when labour *uses* more and better machinery and equipment, labour productivity will rise through capital deepening – hence TFP will not be affected. Thus, "Increasing deployment of IT affects TFP growth only if there are spillovers from IT-producing industries to IT-using industries" (Jorgenson 2001:26).

Baily and Gordon (1988) found productivity gains in the manufacture of computers, but little productivity improvement in their use. Similarly, Gordon (2000b:57) found that the revival in MFP after 1995 was due to technological progress in the *production* of IT, but not the use of IT, so that "three-quarters of all computer investment has been in industries with no perceptible trend increase in productivity".

Pilat et al. (2002:50, box1) provide the OECD definition of ICT-producing industries, which include seven manufacturing and four services industries (4-digit level). The services sector is the IT-using sector *par excellence* and studies found a pick-up in MFP in IT-using sectors, such as those by Triplett and Bosworth (2003:24) and Baily (2002). The service sector is discussed in more detail below.

5.8. Spillover effects

Computer-using industries are able to benefit from the spillover effects from IT investment. The IMF (2000b:50) explains that "*Spillover* effects occur when returns to an investment increase because others make similar investments. Some positive effect is plausible with IT investment – for example, the return to an internet-capable computer rise as more consumers and businesses connect to the internet."

Jorgenson and Stiroh (1999:110) identify the Solow residual with the spillover effect – hence the residual quantifies the spillover effect. Madrick (1998:59) interprets the spillovers as "social returns", returns or "financial advantages that accrue even to those businesses that do not invest in computers". However, the social return on computers will need to be extremely large to make an impact.

However, several considerations contradict the widely held view that computers boost the overall efficiency of the economy. According to Maddison (2001:139), spillover effects have not occurred, largely because of “the costs of absorbing new technologies which have involved a large input of highly trained people, rapid obsolescence of equipment and skills, and some serious blunders, such as those connected with the very costly Y2K scare.”

Similarly, according to Baker (1998b:5), higher productivity growth is accounted for by greater productivity in producing computers and there is a lack of evidence that computers enhance productivity in the production of other goods.

5.9. Aggregate, industry and firm level studies

Productivity studies can be calculated at several levels: the aggregate (national or economy-wide), sectoral, industry and firm (or plant) level. Sectoral productivity analysis can be broken down into the familiar primary, secondary and tertiary levels, but these are typically confined to and focus on agriculture, manufacturing and the services sectors. These studies do not necessarily yield the same results (Brynjolfsson & Yang 1996).

Pritchard (1994:61) frames the productivity paradox in these terms: “How can improvements in performance that occur at one level of analysis seem to disappear when performance is measured at broader levels of analysis?”

Indeed, some firm-level studies (including studies of service and manufacturing firms) have shown positive productivity returns. For example, Brynjolfsson and Hitt (1994:274), in their firm-level study of 367 large firms over the period 1988 to 1992, concluded that IT increases productivity as well as the consumer surplus, but not business profits, as mentioned above.

Bartelsman and Doms (2000) discuss the emergence of firm-level studies with the availability of longitudinal micro-level data to understand productivity. They found that there were large variations in productivity levels between firms, which implies that the assumption of the representative firm underlying aggregation is problematic (Jalava 2002:78).

In terms of measurement issues, Diewert (2000:15) argues that, whereas industry-level studies are riddled with measurement problems (at both conceptual and practical level), studies at national level are easier to measure and are also less prone to measurement problems. The reasons are that the complications arising from the measurement of intermediate inputs are reduced and the “hugely complex web of interindustry transactions of goods and services” (Diewert 2000:15) is simplified at national level.

The main (but not exclusive) focus of the analysis of the productivity paradox takes place at the aggregate level. Sichel (1997a:9) adopts this approach as well. This aggregate focus is crucial to the credibility of the research results, because

> a full accounting of national productivity cannot be obtained by studying just a few different industries … there is more to the macro verdict than a loose collection of micro anecdotes. Focusing on breakthroughs in one endeavour may well miss the compensating costs borne by other segments of society. Beneficial results may still be wanting for the nation as a whole (Roach 1998a:158).

Many “digirati”, a term referring to IT enthusiasts and fanatics (Roach 1998:154), use anecdotal evidence to demonstrate the influence and power of information technology, which is often limited to a few industries.

The above views do not deny that industry-, sector- and firm-level productivity studies are also important – they argue that for productivity to be *sustainable*, aggregate productivity must improve as well.

Baily and Solow (2001) consider international productivity comparisons built from the firm level. They conclude that it is difficult to base comparisons on data at firm level, but nevertheless think that it is a valuable avenue for future investigation.

Finally, Oliner and Sichel (1994:286) observe that computers can be productive at firm level, but not at aggregate level, because “computers are not everywhere” (referring to Solow’s quip) and are a minor factor of production, when judged in terms of their share of current dollar income. They state that this is the key to the resolution of the productivity paradox. The claim that computers are productive at firm level, but not at aggregate level (because they remain a minor factor of production) is not contradictory.

5.10. Computers and the services sector

Although the productivity slowdown can be observed at an economy-wide level, the slowdown is mainly evident in the service sector (Brynjolfsson & Yang 1996). Landauer (1995:76) argues that labour productivity in the services sector failed to respond to the adoption of new investment in computer technology. The productivity revival in 1995 is mainly a revival in service sector productivity.

The problem of measurement is particularly severe in the service sector – hence these two issues are discussed together. In this section the emphasis is on the measurement of services rather than the measurement problem generally. The latter issue will be discussed in more depth in chapter 6, where the major explanations of the productivity paradox are analysed.

Most computers are used in the services sector, because computer equipment is typically deployed in office or office settings. Even in the manufacturing sector, which is outside the services sector, computers are used in an office setting (Sichel 1997a:9).

Services are generally characterised as intangible (Inman 1985b:4), so that “Intangibility of product” is common to all services (Baumol et al. 1989:117). Hill (1977) argues that the output or end product of a service is defined as a change in the condition of a person (resulting in a change in his or her physical or mental condition); or of a good (resulting in a change in the state of the good). In a service, unlike in a good, nothing tangible is actually exchanged between economic agents. Production and consumption of services occur simultaneously and therefore cannot be stocked or stored. It is not true to say that services are perishable (i.e. extinguished or annihilated). They may be temporary (a haircut) or permanent (a medical operation). Services cannot be put in stock or stored, because they are changes in conditions, with varying degrees of permanence.

The service sector has been shown to be a low-productivity sector (in contrast to the high-productivity manufacturing sector); this phenomenon of differential or unbalanced growth is referred to as “Baumol’s disease”, after William Baumol who modelled the result (see Baumol 1967; Baumol et al. 1985). The research found that technologically stagnant sectors, such as personal services, experienced above-average costs and price increases. Baumol, Blackman and Wolff (1989), in a comprehensive overview of the US economy, *Productivity and American leadership: the long view*, similarly argued that services, particularly personal services, are inherently productivity laggards, owing to their technological nature. Ruth Towse (1997) edited an entire volume of studies devoted to Baumol’s model, entitled *Baumol’s cost disease: the arts and other victims.* The literature is briefly reviewed below.

Measurement problems exist in most service industries, where output is difficult to measure (or even unmeasurable), as well as in innovations and new goods and product quality improvements (Triplett 1999a:2-4). For example, the numbers for real output and hence productivity increased after the Boskin Commission (1996) revised the inflation rate downward by an average of 1.1% after the 1970s, when a statistical discrepancy between the product side and income side in the national accounts became evident (Baker 1998c:6). The commission argued that quality improvements were uncounted in the inflation statistics and the consumer price index (CPI) was therefore overstated. Because actual CPI was lower, real GDP growth and productivity were higher compared with the unadjusted numbers. However, the overstatement of inflation applies equally to the post-1973 period as to pre-1973 period, which leaves the unadjusted productivity numbers intact. The commission's work has been criticised and the view adopted that quality changes have been overadjusted. In several publications, Baker (1996; 1998a; 1998d) was particularly critical of the commission’s findings.

Griliches (1994) divides total output into two sectors: “measurable” and “unmeasurable”. “Measurable” sectors are agriculture, mining, manufacturing, transportation and utilities. “Unmeasurable” sectors are construction and the remaining services: trade (wholesale and retail); finance, insurance, and real estate (also known as FIRE); government; and other services. Of interest here is that the “unmeasurable” industries are largely service industries. Griliches argues that the “unmeasurable” sector grew as a share of GDP between 1947 and 1990. Since over three-quarters of computer investment has been in the “unmeasurable” sectors, the productivity effects are “largely invisible” (Griliches 1994:11), which explains the computer productivity paradox.

Many research publications have studied the service sector, as highlighted below. Guile and Quinn (1988) edited a volume of essays dealing with technology and services, entitled *Technology in services: policies for growth, trade, and employment.* The *Canadian Journal of Economics* devoted a special issue to the productivity paradox and the services sector, entitled *Service sector productivity and the productivity paradox* in April 1999. Zvi Griliches (1992a) edited a volume entitled *Output measurement in the service sectors*. These publications underscore the significance of the relationship between productivity and services. In the introduction and overview to the special issue, Diewert and Fox (1999:xiv) remark that distortions in the measurement of productivity cannot account for the abrupt post-1973 slowdown, despite measurement problems.

Sichel (1997b:370), with particular reference to Griliches’ 1994 paper (see above), argues that it is “improbable that mismeasurement of output can explain much of the slowdown (in) aggregate productivity”.

The NRC (1994) examines the impact of IT on the services sector in the USA. The study concludes that IT is an essential rather than an optional component of services companies, because IT provides the “integral infrastructure on which such organisations depend” (NRC 1994:4). It alleges that traditional measures of productivity are unable to capture these essential performance elements (NRC 1994: 4).

There is no doubt that measurement of services output is problematic. Denison (1989:60) opines that a clear distinction should be drawn between service industries and final products that are services. Denison (1989:13-4) proposes that in the analysis of productivity, this distinction must be taken into account. This issue will be discussed briefly. The USA (and other) System of National Accounts (SNO) classifies output according to industries, that is, primary, secondary and tertiary, as well as the respective subdivisions. Denison (1989:14) concludes that “Nearly half the output of service industries consists of inputs into the production of goods and structures”. Thus many services are not end or final products, which are typically used for consumption instead of as intermediate products. In Denison’s calculations services account for only 33% of output if classified in terms of final product, whereas the SNO shows a 59% contribution. Denison argues that the national accounts should be supplemented with a classification based on final product. **Table 4.3** below sets out Denison's calculations.

Table 5.3: "Dividing output": nonresidential business GNP (1982)		
%	Classification of output by industry as in the US SNO	Classification of output by end (final) product
Commodity-producing industries (goods and structures)	40.6	67.3
Service industries	59.4	32.7
Source: Denison (1989:13-14 & 60)		

Baumol's unbalanced productivity model states, that from a productivity perspective, there are generally three types of economic activities: stagnant activities, progressive activities, and a combination of these, asymptotically stagnant activities (also referred to as initially progressive activities).

Progressive activities are characterised by "innovations, capital accumulation, and economies of scale (which) all make for a cumulative rise in output per man hour" (Baumol & Oates 1975:241). Stagnant activities "by their very nature, permit only sporadic increases in productivity." Their output is not standardised and mass production is difficult; and there is an "intimate connection between the quantity of labour used in supplying them and the quality of the end product." (Baumol & Oates 1975:241-242). In his initial formulation, Baumol (1967:415) stated that regarding economic services, such as municipal government, education, the performing arts, restaurants and leisure time activity: "inherent in the technological structure of each of these activities are forces working almost unavoidably for progressive and cumulative increases in the real costs incurred in supplying them."

Stagnant activities often show extremely high productivity increases and falling costs in the initial stages of their development, but over time, they "necessarily approach that of the stagnant sector" (Baumol et al. 1985:806.). Other examples of stagnant activities are the mass media, sound recordings, film, radio, television broadcasting and IT industry (i.e. hardware and software).

To illustrate, one could compare manufacturing to the performing arts (or more generally, personal services). The productivity story of the performing arts is thus emblematic of the services sector as a whole. Manufacturing, as illustrated by watchmaking, is a technologically progressive activity; but the services sector, as illustrated by the performing arts, is a technologically stagnant activity (Baumol 1987:842):

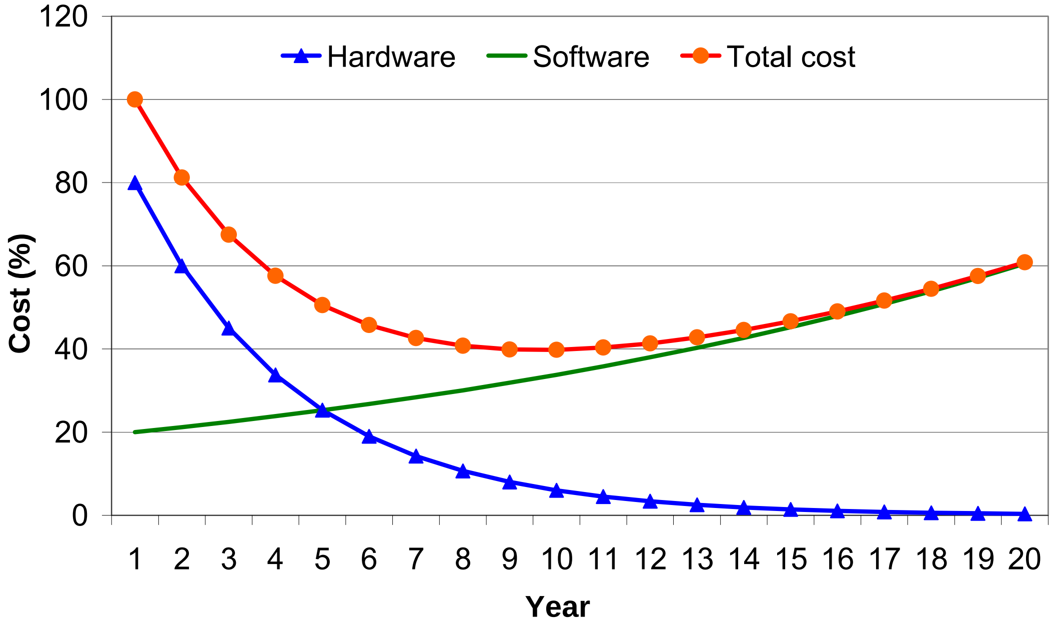
> There has been vast and continuing technical progress in watchmaking, but live performance benefits from no labor-saving innovations – it is still done in the old-fashioned way. Toward the end of the 17th century a Swiss craftsman could produce about 12 watches per year. Three centuries later that same amount of labour produces over 1200 (non-quartz) watches. But a piece of music written three centuries ago by Purcell or Scarlatti takes exactly as many person hours to perform today as it did in 1985 and uses as much equipment.

Baumol's model can be applied to computerisation (see **figure 5.2**). Hardware is classified as a progressive activity; software as a stagnant activity; and the computer sector (hardware plus software) as an asymptotically stagnant activity.

Thus the overall costs of computerisation will approach that of the stagnant component, software. Rising software costs will eventually overwhelm falling hardware costs, driving up total costs, so that the computer industry will become "asymptotically stagnant".

A similar argument is applied to an economy as a whole: the stagnant services sector will dominate the progressive manufacturing sector and the economy as a whole will become asymptotically stagnant over time. Therefore, alarmingly, Baumol's model, when applied more generally, predicts that "the growth rate of the economy will asymptotically approach zero" (Baumol 1967:419)! The long run outlook for the economy is dismal: according to the model's founding father, there is no real cure for the disease, only palliatives (Baumol & Oates 1972:52).

Figure 5.2: Asymptotically stagnant activities: a simulation*



Source: Based on Baumol & Baumol (1985:186-188 & figure 3); Note: **Hardware costs fall 25% p.a. and software costs rise 6% p.a. in real terms. Hardware costs initially constitute 80% of total costs.*

However, Triplett and Bosworth published a paper in 2003, which announced that "'Baumol's Disease' has been cured". They argued that after 1995 labour productivity in many services sectors doubled compared to the 1973-1995 period and equalled the economy-wide average (Triplett & Bosworth 2003:23). Similarly, Varian (2004) claims that "Baumol's disease appears to be in remission, at least for a significant number of service industries."

In a subsequent paper, Nordhaus (2006) finds in favour of Baumol's view that technologically stagnant activities, such as personal services, experienced above-average cost and price increases. According to Nordhaus (2006:1), services will represent a growing share of national output over time and therefore slow down aggregate productivity growth.

The service sector contains several subsectors with different productivity profiles. One such subsector has shown high productivity growth since 1995. According to Lewis (2004: 91), retailing and wholesaling (general merchandise retailing) accounted for half of overall productivity growth acceleration in the mid-1990s. This jump in productivity growth is referred to as the "Wal-Mart effect", after innovations (such as barcodes, electronic merchandise tracking and logistics management) by Wal-Mart (a large chain of retail stores across the USA) were captured in the national productivity statistics (Lewis 2004:91). As Rogoff (2006) remarks: “The US productivity miracle and the emergence of Wal-Mart-style retailing are virtually synonymous”. Lewis (2004:88) concludes that increasing competition in the microprocessor industry rather than Moore’s Law underpinned the productivity acceleration: “It is ironic that in perhaps the most ‘new economy’ of all sectors the accelerated productivity growth rate for the late 1990s came not from anything new but from a straightforward increase in competitive intensity.”

It was not “new economy” technology that propelled Wal-Mart into the forefront, but old style IT applications (Lewis 2004:94).

5.11. Productivity, technical change and the “residual”

Solow’s ground-breaking work showed that there was an unexplained residual after the growth in capital and labour inputs had been accounted for in explaining output growth. The residual needed to be explained and technical change or productivity became the prime candidate to explain the residual. The two were used almost interchangeably (Mokyr 1990a:7). Thus technical change is typically equated with the residual and analysing technical change has become a vital subject in economic research.

The residual, interpreted as TFP growth, can be negative. For example, a growth accounting exercise of the Democratic Republic of the Congo (DRC, the former Zaire), revealed that the residual was negative. Output per worker fell by 3.3%, with the contribution of physical capital falling by 1.2% and the contribution of TFP by 2% from 1960 to 2000 (Akitoby, & Cinyabuguma 2004:21). Similarly, a study by Akinlo (2005:14) found that the average TFP growth rate was negative for 17 of the 34 Sub-Saharan African countries included in the study from 1981 to 2002.

The residual has a history dating back to 1937, but it was codified by Solow (Griliches 1995). Research into the residual have been ongoing since the 1950s with similar research conducted by Abramowitz (1956), Denison (1962), Kendrick (1961) and Jorgenson and Griliches (1967). Generally, their research argued that modern economic growth in the US economy should mainly be attributed to increases in the efficiency and not the quantity of the employment of capital and labour resources.

By the early 1960s, technological change had acquired several synonyms. According to Domar (1961:709) these “have ranged from ‘output per unit of input,’ ‘efficiency index,’ ‘total factor productivity,’ ‘change in productive efficiency,’ ‘technical change,’ all the way to ‘measure of our ignorance’”. Domar (1961: 709 & footnote 7), however, prefers to call it the “residual” for the following reason: “It is indeed estimated as a residual after the contribution of other inputs to the growth of output has been accounted for.” Technical change is of course Solow’s (1957) term, whereas the oft-quoted “measure of our ignorance” was coined by Abramovitz (1956). Jorgenson and Stiroh (1999:110) identify the residual with the quantification of spillovers and believe that Solow (1957) “showed that these spillovers appear as residual economic growth after the growth of all other inputs, including inputs of IT equipment, are taken into account”.

Productivity and technical change are not identical concepts, but are closely related (Schreyer & Pilat 2001:157-159). Salter (1960) analyses the relationship between productivity and technical change. Productivity, being a much broader concept and having a multitude of meanings, comprises all the dynamic forces of economic life, such as “technical progress, accumulation, enterprise, and the institutional patterns of society” (Salter 1960:1). Salter (1960:26) argues that “technological advances make possible new levels of productivity”.

Basu and Fernald (1997:1) point out that the productivity residual and technical change are distinct, not identical concepts; and only in an economy without distortions does the productivity residual index accurately reflect technological change.

According to Maddison (1995:33), “technological progress has been the most fundamental element of change” compared to the other major factors of growth performance in the world economy from 1820 to 1992: accumulation of physical capital with embodied technical progress; improvement in human capital; and integration with the world economy through trade in “goods and services, investment, and intellectual and entrepreneurial interaction”. He argues that although technological progress is difficult to measure, its long-term impact can easily be illustrated.

Since the residual is thus largely that part of economic growth left unexplained by employing more labour or capital, it can be regarded as a “free lunch” (Mokyr 1990a:7).

In 1981, before his famous quip, Solow made the following remarks about the residual (Baily 1981a:58):

> A productivity puzzle is said to exist when all the measurable causal factors that can be mustered are only able to account for a fraction, say half, of the observed deceleration in labour productivity. The rest is left as an unexplained deceleration of the growth of the residual. To solve the productivity puzzle is to explain in some other way that remaining half of the deceleration. … My impression is that the residual moves with some irregularity. Almost the only constant growth rate one could imagine for it is zero: a number growing like a pure exponential could hardly be called a residual, except for the limiting case that there is no residual.

5.12. Diminishing returns

A further complication has often been raised: diminishing marginal benefits of IT investment.

Diminishing returns are not uniquely linked to computers, but are a general characteristic of all capital. Solow (1994:48) argues as follows: “Diminishing returns to capital implies that the long-run rate of growth is completely independent of the savings-investment quota.”

Gordon (2000b:60-63) contends that diminishing returns are pervasive and thus necessay for understanding the productivity paradox because of the “unprecedented speed with which diminishing returns have set in” and “sheer pace at which computer users are sliding down the computer demand curve to ever-lower marginal utility uses”. Gordon (2000b: 65) also argues that diminishing returns to IT investment may have already started and that the “productivity gains of computers have already been achieved”.

Similarly, Stiroh (2001e:21) argued that since computer prices have declined at such a rapid pace, computers can be used for pursuits characterised by low productivity and low efficiency.

5.13. Declining prices and rising investment

An important economic factor influencing IT investment is the steep decline in computer and peripheral equipment prices. This decline is mostly accounted for by the combination of a rise in demand and a fall in costs of IT devices (Jonscher 1994:23).

Falling computer prices have presented the national statistical agencies with a new problem. Young (1989:115) sums up the problem as follows: “The computer represents a rate of technological change that, compared with the past, is unusual and that, more importantly, has not previously been faced fully either by the GNP estimator or by the productivity analyst.”

According to Denison (1989:15-17), as a result of the improvements in the design of computers and their components, their power has risen greatly “without a corresponding increase in the labor and capital required to produce them.” Therefore productivity in the production of computers has increased vastly.

Table 5.4: Business purchases of computers (inflation adjusted)

Year	Amount invested (US$)
1960	0
1969	$100 million
1972	$200 million
1973	$200 million
1976	$300 million
1979	$1.5 billion
1980	$2.4 billion
1990	$29.4 billion
1997	$224.7 billion

Source: Madrick (1998:56, table 3)

The steep decline in computer prices thus resulted in a large increase in spending on computerisation. Expenditure on computers and peripheral equipment by businesses has soared, particularly since the 1960s. According to Madrick (1998:56), inflation-adjusted purchases of computers, which amounted to only US$100 million in 1969, rose to US$224.7 billion in 1997. **Table 5.4** gives a more complete picture.

Despite the rapid growth in investment spending on computerisation, there are two opposing views of the IT revolution: the one view sees IT as having a revolutionary impact, changing the shape of things to come; whereas the other view regards IT largely as a huge letdown, whose actual performance has been disappointing and does not measure up to the great inventions of the past (Gordon 2000b).

A decrease in computer prices – as usually referred to in the productivity literature – does not mean that the prices actually paid for computers in shops have fallen; because prices are hedonic prices, it means that prices of "computer attributes like a given level of speed, memory, disk drive access speed and capacity, presence and speed of a CD-ROM, and so on" have declined (Gordon 2000b:50).

Declining ICT prices have played a decisive role in investment decisions. Jorgenson and Stiroh (1999:109) argue that the quick adoption of ICT technology is a result of the rapidly falling prices of ICT capital, so that ICT capital is substituted for other more "expensive" forms of capital and labour.

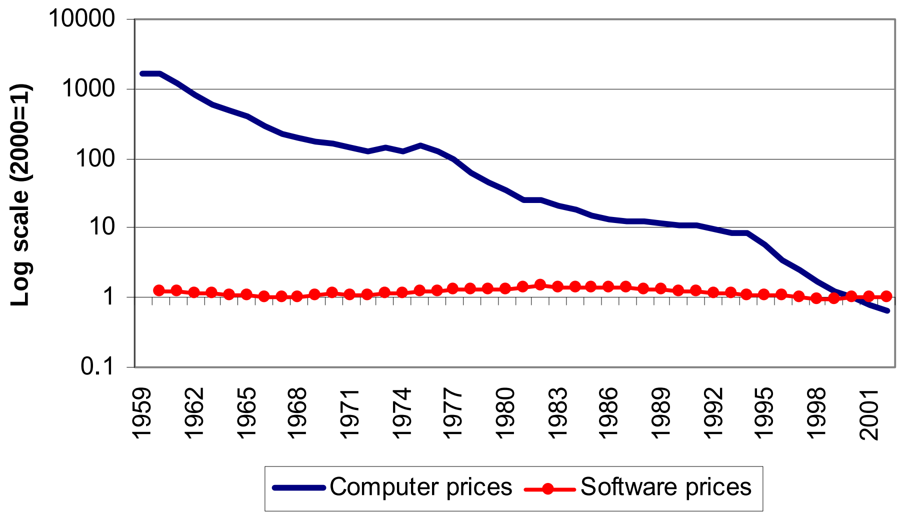
Substitution should be placed in a broader economic context of investor and consumer behaviour (Survey of Current Business 1985:14):

> Typically the effect of shifting to a recent base period is to reduce the rate of growth. … *It is true generally* … that a recent base period produces lower growth in real GDP than an early base period, *if* there is a tendency for slow-growing quantities to be associated with relatively fast-growing prices and for fast-growing quantities to be associated with relatively slow-growing prices.
>
> Over long timespans, such inverse relationships tend to be the rule. As changes in technology or in market structure lower some relative prices and raise others, buyers respond by demanding relatively more of the low-priced goods and relatively less of the high-priced ones. *Computers provide a dramatic example of technological change that lowers a relative price and leads to rapid growth in demand (Italics added).* It is possible for shifts in demand due to changes in taste or in income levels to have a contrary effect, driving both prices and quantities up for some commodities more than for others. Apparently such shifts have tended to be less important over long timespans than the factors producing the inverse relationships of price and quality changes.

The above quote refers to the importance of index numbers – the base year effects - discussed in chapter 3 under the heading “Index number bias”.

Bresnahan and Gordon (1997:23) note that computers are characterised by “a continuing decline in the price-performance ratio”. Just how fast computer hardware prices have declined can be gleaned from **figure 5.3** below. Calculations by Jorgenson (2005: table 2.1) show that computer prices (normalised to 1 in 2000) declined from 1,635.06 in 1959 to 0.64 in 2002.

Figure 5.3: Declining computer hardware and software prices



Source: Jorgenson (2005: table 2.1)

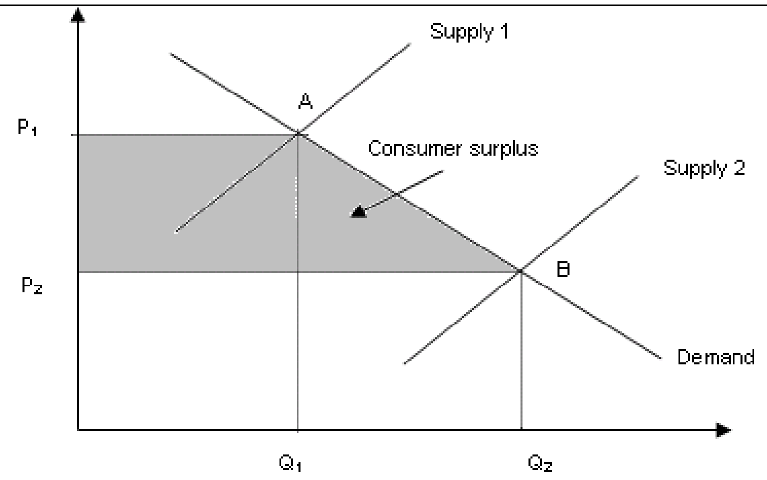
Software prices for PCs, like hardware prices, also declined when adjusted for quality changes, and by 2.7% per year between 1987 and 1993. Over this period the GDP deflator increased by 3.5%, which implies that PC software prices fell by 6.2% in real terms (Sichel 1997a:56-57). According to Sichel (1997a:57) other authors found similar declines in PC software prices.

The computer supply and demand curve, based on Sichel (1997a:16-17) and Gordon (2000b:60-62), is shown below (**figure 5.4)**. Declines in computer prices are mainly driven on the supply side (Sichel 1997a:17), so that a downward-sloping demand curve based on falling computer prices (the blue solid line in **figure 5.3**) can plausibly be drawn. Brynjolfsson (1996:289-290) believes that technological advance suggests outward shifts in the supply curve year after year (e.g. Supply 1 to Supply 2 in small increments over time in **figure 5.4**). This maps out or reveals the underlying demand curve (see Brynjolfsson 1996:289, figure 7). The demand curve does not shift at all. Brynjolfsson (1996:291) estimated the price elasticity of demand for computers economy-wide at –1.33 (and income elasticity at 3.45) for the 1970 to 1989 period.

The consumer surplus is shown as the shaded area P_1ABP_2 (Sichel 1997a:31).

The declining cost of computer power has been cited as a factor in the explanation of the paradox; however, this has been debunked because diminishing returns (discussed above) and declining marginal utility of computing power cancel out price benefits (Gordon 2000b:62).

Figure 5.4: Supply and demand for computers: a conceptual view



Source: Reproduced from Sichel (1997a:17, figure 2-2)

Also, declining computing prices have led to the substitution of IT equipment for other more expensive forms of capital and labour. According to Jorgenson and Stiroh (1999:109), this process of substitution has not resulted in "technical change" as defined economically, because "substitution represents movement along a given production function, while technical change corresponds to a shift in the production function … Technical change occurs only if more output is produced from the same inputs". These authors believe that this explanation provides a straightforward solution to the productivity, accounting for the high levels of IT investment but slow productivity growth. This interpretation also prompted Triplett (1999b:314) to state that "the economic impact of the computer is not a productivity story at all".

Falling computer prices, which is based on quality adjustments, introduce "non-sense" into the GDP numbers. Baker (1998b:7) is in complete disagreement with quality adjustments and argues that “The *only* measure of the quality of an investment good is its ability to produce revenue. Whatever else it can or cannot do is irrelevant from an economic perspective.”

5.14. Software reclassified

One weakness of the studies on the productivity paradox is that they sometimes ignore or underestimate the role played by software, as well as labour inputs. The omission of some IT inputs could distort the productivity measurement, because an understatement of inputs will result in an overstatement of productivity (NRC 1994:35).

An analysis of the computer revolution should include software and computer-related labour inputs as well as hardware. Sichel (1997a:10 & 65) points out that “all tasks done with a computer require a combination of hardware, software, and labour inputs”. The combination of hardware, software and other expenses, including labour, is referred to as computing services (Sichel 1997a: 65).

Lichtenberg (1993:8) states that labour costs make up over 40% of IT budgets. It is necessary to include all the factors that computers require to function in the study of the computer revolution: hardware, software and computer-related labour inputs (Sichel 1997a:10). Obviously, computer software enables hardware to produce useful output (McCarthy 1997:5).

Sichel (1997a: 65) reports that surveys of ICT departments of large US companies (from 1976 to 1984) showed that the spending on hardware accounted for 38% of their budgets, whereas software accounted for 28% and labour and other expenses for 34%. Generally, software is extremely expensive to develop but costs almost nothing to produce (Krugman 2000:F-16).

In a major change in the US NIPAs in 1999, computer software was reclassified in the national accounts. Previously, computer software purchases had been classified as intermediate inputs (CBO 1998:v). After the October 1999 comprehensive national accounts revision, software was classified as fixed investments (Grimm et al. 2002:11). The US Congressional Budget Office (CBO 1998:v) argues that “software spending generally fits the definition of an investment”, because software “like other capital expenditures, provides a flow of services that lasts more than a year” (Kliesen 1999:1). According to Spant (2003:41): “This had the effect of increasing total nominal investment in current dollars in 1999 by an estimated 95 billion dollars in the private sector and by 20 billion dollars in the public sector. Taken together, it increased recorded nominal and real GDP by around 1.5 per cent.”

Thomas (2003:48-49) comments that reclassifying software shifted it from the income statement to the balance sheet, resulting in: (1) software no longer being a business expense, thus lowering operating costs and raising profits, but (2) also raising investment levels, real GDP growth and total assets.

It is important to note that this change had an asymmetrical impact on gross domestic product (GDP) compared to net domestic product (NDP), raising NDP only marginally because of increased depreciation. Depreciation of computers will be further discussed in the context of gross versus net measures of national output or product in chapter 6.

Anselmo and Ledgard (2003:125) argue that software productivity is measured by functionality, complexity and quality. They also note that (Anselmo & Ledgard 2003:121): "software productivity has been dropping more rapidly than any other industry. The semiconductor industry had the most productivity growth (86%) from 1990 to 1995. In that same period, productivity for the software industry decreased by 10%, indeed, the worst decline of all industries."

The treatment of software as investment is controversial. Denison (1989:10) emphasises that there should be a clear distinction between the determinants of the advances in knowledge and the determinants of saving and investment; the "effect of the misclassification is to make growth analysis chaotic". Denison was therefore opposed to "changes in national accounting which treat accretions of knowledge as investment" (Maddison 2005:4).

Maddison (2005:4), adopting Denison's view, argues that: "the only form of knowledge which is now treated as investment is computer software. It is odd to treat this rapidly depreciating knowledge as investment, whilst ignoring the more durable influence of books and education".

5.15. The internet and the "new economy"

The rise of the internet therefore coincides with productivity acceleration in 1995. It is therefore worth considering the internet briefly in relation to productivity, because computers and peripheral equipment, software and communications equipment comprise the basic internet infrastructure. There is a wealth of literature on the economics of the internet.

The internet is regarded as the main but not the only embodiment of the so-called "new economy". The term "new economy" has several synonyms; the "internet superhighway"; the "new era economy"; the "network economy"; the "knowledge or information economy"; the "digital economy"; etc. The new economy – based on ICT and the internet – has been compared to the Industrial Revolution and referred to as the third industrial revolution (also the digital or IT revolution), thus underscoring its significance and widespread impact on how business is conducted (Mahadevan 2002:60). Some authors thought that a frictionless economy would evolve in which inflation would disappear and business cycles would end (Shiller 2005:119).

The new economy started to flourish in about 1995 (Spant 2003:41) and its mantra, according to Jorgenson (2001:2), is "faster, better, cheaper". It was claimed that a new economic paradigm was emerging, which would radically and qualitatively change the rules of the game (Krugman 1997a:124).

The influential new economy magazine *Wired* published “New rules for the new economy”, which captures the spirit of the network economy: “This emerging new economy represents a tectonic upheaval in our commonwealth, a social shift that reorders our lives more than mere hardware or software ever can” (Kelly 1997:141). Kelly lays down 12 principles for surviving in this new and turbulent world.

The subcomponents of the new economy are e-commerce; e-business; business-to-business e-commerce (B2B); business-to-consumer e-commerce (B2C); and others. E-commerce is largely characterised by business-to-business or intermediate transactions in consumer spending on services and hence little of the new economy shows up as final demand (Landefeld & Fraumeni 2001:28). The internet’s actual size is still relatively small. In 1998 it contributed some US$159 billion or 1.8% to GDP and e-commerce sales were estimated at 1.01% of retail sales (Landefeld & Fraumeni 2001:26).

In an important paper, Landefeld and Fraumeni (2001) provide guidelines on the measurement of the new economy. The issues raised are beyond the scope of this study, but the authors provide an estimate of the size of the internet economy for 1998 (**table 5.5**).

Litan and Rivlin (2001) projected the economic impact of the internet and found that: (1) it has a real potential to raise productivity growth; (2) its impact is likely to be felt in “old economy” areas (health care, government); (3) it could expand the scope of management efficiencies; and (4) the bulk of the internet’s benefits will accrue to consumers in the form of greater convenience and more choice.

The optimism sparked by the new economy gave rise to the stock market boom, especially on the technology-intensive Nasdaq exchange, which eventually collapsed in 2000. Many of the new principles adopted by investors led to the overvaluation of stock prices (in terms of P/E ratios), which ultimately reverted to valuations more in line with historical valuations when the speculative bubble burst. Investors were encouraged by publications such as *Dow 36,000* by Glassman and Hassett (1999), which proposed a new theory of stock evaluation and claimed that stock prices would rise dramatically in the ensuing years. However, many new economy listings disappeared entirely after the market crashed. The “dot com bubble”, as it was dubbed, inspired a wealth of literature: see for example Robert Shiller’s *Irrational exuberance* (2005). Irrational exuberance – a phrase made famous by Alan Greenspan (1996) in a televised speech – was partly based on the labour productivity gains that started in the late 1990s (Shiller 2005:119).

Table 5.5: Estimates of the internet economy (1998)				
Layer	Description	Internet revenues (billions) (est.)	GDP share	Contribution to GDP (billions)
One	Infrastructure	$115.0	0.37	$43.1
Two	Applications	$56.3	0.60	$34.0
Three	Intermediary	$58.2	0.18	$10.3
Four	Commerce	$101.9	0.70	$71.4
	Total	$331.4	……….	$158.8
Source: Landefeld & Fraumeni (2001:26, table 1)				

Stiroh (1999), however, contends that the new economy, based on increasing globalisation and an expanding information technology, can adequately be explained by the principles of old economics. In an influential article published in the *Harvard Business Review*, "How fast can the U.S. economy grow?", Paul Krugman (1997b:123-129) criticised new era economics, stating that "the new paradigm simply does not make sense" (Krugman 1997b:124).

New era thinking has many historical precedents and is typically inspired by a new technological breakthrough. The same clichés seem to be repeated over and over (Bernstein 1992:159): "In the new economy, many of the old classical rules of economics no longer apply; over the years the U.S. has made and learned new rules all its own." This quote is taken from *Time* magazine published on 31 December 1958! The idea of a new economy is certainly not a modern concept and new era economic thinking has recurred frequently (Shiller 2005:106-143). Sornette (2003:267) discusses the similarity between various stock market crashes and found that a number of crashes had common characteristics: in 1962 "The 'tronics boom,' as it was called, actually has remarkably similar features to the New Economy boom preceding the October 1929 crash or the New Economy boom of the late 1990s, ending in the April 2000 crash on the Nasdaq index".

Sornette (2003:270) also found that the average investor is motivated by future expected earnings and capital gains, whereas actual economic conditions play a secondary role, an attitude that can easily lead to speculative bubbles. New era thinking – inspired by the productivity acceleration in the mid-1990s - played some part in raising expectations of higher future earnings and capital growth. The optimism turned negative when, like all speculative manias, the bubble burst, financially devastating many investors and firms.

5.16. Conclusion

This chapter provided an overview of the many facets of the economics of productivity. Despite the different approaches to productivity analysis, which this chapter aimed to discuss, and despite the data revisions, investors interpreted the 1995 productivity revival as heralding a new economic era, but which ultimately led to irrational exuberance in stock valuations and the stock markets' collapse in 2000.

The next chapter looks at how productivity and computerisation are captured in the national income and product accounts (NIPAs).

6. CHAPTER 6: MAJOR EXPLANATIONS OF THE PRODUCTIVITY PARADOX

6.1. Overview

Previous chapters provided background information on and discussed conceptual tools on various productivity-related topics, index numbers, ICT in the US national accounts and the economics of ICT and productivity. This chapter examines the principal explanations of the productivity paradox. The secondary explanations are examined in Chapter 7. The Solow computer paradox studies the apparent conflict between the sudden decline in measured productivity growth and the coincident rise in ICT investment in the 1970s. The principal explanations can loosely be grouped together, firstly, into the philosophical or methodological hypothesis and, secondly, into the mismeasurement hypothesis.

These explanations may overlap to some extent. For example, quality change issues and the intensive employment of computers in services are closely related, because ICT is used intensively in the services sector where quality change is difficult to measure. In the literature, however, these two aspects are often treated separately, depending on the focus of the research.

6.2. Principal explanations of the productivity paradox

Significant papers by Baily and Gordon (1988) and Gordon (1996) on measurement issues and computer power, and performance of the service sector in the USA, provide a conceptual framework to analyse the possible candidates for the computer-related slowdown in productivity growth. The classification in **table 6.1** is based on:

(1) whether the explanation can account for the impact on an aggregate or sectoral level;

(2) whether the explanation applies to the post-1973 period only or the pre-1973 as well as post-1973 periods.

These papers argue that only explanations consistent with quadrant A (see **table 6.1)** are candidates that can help to explain the productivity slowdown (Baily & Gordon 1988:349; Gordon 1996:18). Issues that are raised in quadrant C merely "reshuffle the industry allocation of productivity change" (Gordon 1996:18). Explanations in quadrants B and D are not candidates for the productivity slowdown either, but they may be of interest to the calculation of the inflation rate. The Boskin Commission (1996) dealt with the problem of the accuracy of the calculation of consumer inflation in detail, which is discussed in more detail below.

Table 6.1: Classification of measurement error candidates	
A Affects aggregate economy, contributes to post-1973 slowdown	**B** Affects aggregate economy, but same effect pre-1973 and post-1973
C Contributes to post-1973 slowdown for an industry, no aggregate impact	**D** Measurement error that applies pre-1973 and post-1973, no aggregate impact
Source: Gordon (1996:18); Baily & Gordon (1988: 349)	

The slowdown in productivity is not restricted to the USA: many other developed countries, mainly OECD members, also experienced a productivity slowdown after 1973. According to Arnold and Dennis (1999:9), "productivity growth slowed in virtually all advanced countries at about the same time and was generally more severe in countries other than the United States".

The productivity slowdown in several countries after 1973 could mean that a common factor is responsible. Nordhaus (1982:140) asks whether an explanation should incorporate such a pervasive factor: “Given the universality, simultaneity, and depth of the productivity slowdown, it seems that we should look first for common explanations.”

Another possible factor is the sectoral shift from the manufacturing sector (characterised by "tangible" output) to the services sector (characterised by "intangible" output). The stylised facts are that the manufacturing sector is typically a high productivity sector, whereas the services sector is a low productivity sector. Most OECD countries experienced such a shift during the period under discussion.

To extend Gordon’s and Baily and Gordon’s arguments (see **table 6.1**), any credible explanation should account for the “clean break” of lower productivity growth in 1973, as well as the sudden upward surge in 1995. Thus any parameter that may have been mismeasured or otherwise influenced the productivity numbers, must be shown to have undergone a sudden change. The clean break is evident from the post-war figures, which were shown in chapter 4.

One problem with many explanatory hypotheses is that the reasons provided are much more likely to take effect gradually than to cause a sudden reversal (Denison 1979a:122). Indeed, why should economic growth proceed smoothly, without being uninterrupted? According to Metcalfe (1987:617): “Knowledge-driven economic growth is not a smooth affair with each activity advancing in step. Rather, as Schumpeter insisted, it involves disharmony and fierce competition between the new and old, a diversity of sectoral growth rates and profit rates and continual reallocation of labour and capital between activities.”

6.3. The philosophical hypothesis

The philosophical or methodological hypothesis is the general, meta-level and theoretical critique of productivity analysis in the context of the neoclassical paradigm. The main explanation of the paradox in the neoclassical framework is the mismeasurement hypothesis, which is examined below.

The philosophical critique states that the neoclassical research programme is flawed because neo-classical assumptions are unrealistic. The neoclassical framework has been much criticised. The framework's assumptions, such as perfect competition, constant returns to scale, etc. have been rejected by many economists. Indeed, many analytical models are based on neoclassical assumptions (see, for example, Oliner & Sichel 2002b:16).

Generally, Blaug in his *Economic theory in retrospect* (1996: 693) argues as follows:

> The besetting methodological vice of neo-classical economics was the illegitimate use of microstatic theorems, derived from 'timeless' models that excluded technical change and the growth of resources, to predict the historical sequence of events in the real world. A leading example of this vice was the explanation of the alleged constancy of the relative shares of labour and capital by the claim that the aggregate production function of the economy is of the Cobb-Douglas type, although the theory in question referred to microeconomic production functions and no reasons were given for believing that Cobb-Douglas microfunctions could be neatly aggregated to form a Cobb-Douglas macrofunction.

We saw that the production function approach is largely based on neoclassical assumptions. Barro and Sala-i-Martin (1995:11) argue as follows:

> The inclusion of technological change in the neoclassical framework is difficult, because the standard competitive assumptions cannot be maintained. Technological advance involves the creation of new ideas, which are partially nonrival and therefore have aspects of public goods. For a given technology … it is reasonable to assume constant returns to scale in the standard, rival factors of production … But then, the returns to scale tend to be increasing if the nonrival ideas are included as factors of production. These increasing returns are in conflict with perfect competition.

At the most fundamental level, the production function and growth accounting approach have one thing in common: they are supply-side approaches, with no reference to the demand side. In a review of Denison's 1967 work, *Why Growth Rates Differ*, Harrod (1969:324-25) commented as follows:

> In my opinion the course of demand has been much the most important determinant of growth … the point is that producers will not take the trouble to increase their supply

> potential, whether by capital investment, or by managerial reorganisation … if they see no prospect of selling the extra output from their doing so.

Nelson (1973) criticises the growth accounting framework and argues that it may be impossible to distinguish between a movement along the production function and a shift in the function, which is an essential feature of the Solow analysis of technical change (see Solow 1957:320). Rymes (1972, 1983) contends that the Solow model is flawed and the distinction between technical change (shift in the production function) and capital accumulation (movement along production function) cannot be used.

Denison (1987:574) countered the objection of economic interaction between determinants by saying that it poses no serious threat to growth accounting and to abandon the analysis would be tantamount to abandoning quantitative analysis of growth and growth policy.

In practice, it is difficult to distinguish between capital accumulation and productivity growth for the following reasons: "First, technical advances might be embodied in new capital. Second, by raising the returns to capital, increased TFP might induce greater capital accumulation. Thus as a point of departure, it is worth asking whether the growth accounting exercise actually yields a meaningful decomposition" (Collins & Bosworth 1996:164).

Romer (1987) argues against the theoretical foundations of growth accounting and attacks the constant returns to scale assumption. Instead, he introduces a growth accounting model with increasing returns to scale.

The story of productivity and of the computer paradox as reflected in the official statistics is coherent, but if tested against ultimate (rather than proximate) foundations, faces serious philosophical and methodological challenges. This argument reduces to "coherentism" versus "foundationalism" (see Blackburn 1996:67 & 145). Blackburn (1996:145) defines coherentism as the view that "a body of propositions may be known without a foundation in certainty, but by their interlocking strength, rather as a crossword puzzle may be known to have been solved correctly even if each answer, taken individually, admits of uncertainty".

Despite philosophical challenges, the NIPAs and their methodological building blocks provide a coherent picture, albeit grounded on several contestable foundations.

6.4. The Cambridge Controversy

The aggregation problem discussed here is the *production function aggregation problem*. The *sectoral aggregation problem* will be considered in a later section.

The production function aggregation problem is also known as the Cambridge Controversy, which raged in the 1930s between the Cambridge School of Economics (CSE) in the UK and the

Massachusetts Institute of Technology (MIT) at Cambridge in the USA. The former school, which included Joan Robinson (see quote below) and Kaldor, was highly critical of the MIT school, represented, among other, by Solow and Samuelson.

The main focus of the CSE's attack was on growth theory based on the aggregate production function. According to the CSE, reswitching of production techniques rendered the neoclassical approach invalid. Briefly, reswitching means "the possibility that the same capital to labour ratio can be associated with two relative prices of capital to labour (Pearce 1992:301). MIT thought that although reswitching weakened neoclassical theory, it did not invalidate all neoclassical theory. The CSE school of thought doubted whether the aggregate function existed at all (Pearce 1992: 49, 51 & 375). Blaug (1992:171) summarises the problem and argues that the neoclassical productivity analysis was nothing more than "measurement without theory", which is based on the following: "The notion that the functional distribution of income may be explained simply by invoking the principles of marginal productivity, as enshrined in an aggregate production function of the simple Cobb-Douglas variety."

Furthermore (Blaug 1992:171):

> After Solow's seminal article of 1957, estimation of aggregate production functions for purposes of measuring the sources of growth and drawing inferences about the nature of technical change became a widespread practice in economic research, ignoring the profound difficulties that surround the entire concept of an *aggregate* production function.

However, Grunfeld and Griliches (1960) examine the "micro" versus the "macro" issues and claim that there could be an aggregation gain rather than an aggregation error. The authors argue that aggregation of economic variables can reduce specification errors that occur in empirically-estimated microeconomic relations of individual consumer or producers.

It would be difficult, if not impossible, to avoid some use of aggregate methods. As Hahn and Matthews (1964:888) argue in a major survey of the theory of economic growth: "For it seems fairly clear that any confrontation of theory with fact will have to proceed by the use of some aggregative methods." They argue that crude theoretical constructs should be found that can adequately deal with the crude evidence, rather like "plumbers use a spanner".

Indeed, a practical orientation to find usable solutions has been adopted instead of abandoning the research project in the light of abstract objections.

In a review of the literature on production functions, Griliches and Mairesse (1995:2) contend that the production function "is a tool, a framework for answering other questions, only partially related to the 'production function' itself". They focus on the "identification problem" associated with Cobb and Douglas's (1928) work on the production function. The Cobb-Douglas function is examined in more detail below.

6.5. The Cobb-Douglas production function

The Cobb-Douglas function makes the following assumptions: competitive markets, constant returns to scale, neutral technological change, and constant shares of the factors in national income (NRC 1979:44).

Of course these are extremely restrictive assumptions. However, other functional forms of the production function, such as the translog function, are more flexible and

> allow for economies of scale, variable elasticities of substitution between the factors, and "biased technological change," which means that changing technology may increase the demand for one factor relative to another. Under the latter assumptions, the shares of the factors in national income (factor cost) may be changing over time. This implies either a constant elasticity of substitution that differs from unity or a variable elasticity of substitution. (NRC 1979:44).

The Cobb-Douglas function has not only been criticised but indeed ridiculed. Robinson (1955:71) states the following:

> The fallacy at the root of the production function is the idea that it is possible to specify purely technical relations, not involving prices, in a human economy. Even Robinson Crusoe does not provide an example of an economy for which this is valid. … Only … living in a timeless present, satisfy the conditions required for the neo-classical analysis of production to make sense.

Another instance is the invective directed against the production function by Shaikh (1987:690-691) where he refers to the "humbug production function" in an article in the authoritative *New Palgrave dictionary of economics* (Eatwell et al. 1987). Although Solow (1974:121) replied to an earlier version (Shaikh 1974) of this critique, the criticism has sometimes been repeated.

Griliches and Mairesse (1995:2) examine the objections to the Cobb-Douglas function, in particular the argument that the production function is not "identifiable" – that is, the right-hand side variables (the explanatory variables) are not independent variables but are highly correlated with one another. This statistical problem is known as multicollinearity, which implies that the regression model has difficulty isolating which explanatory variable influences the dependent variable (Koop 2000:88). The issue of multicollinearity is also part of the hedonic regression techniques discussed below (Triplett 2004: chapter VI).

Phelps Brown (1957:551) analyses the Cobb-Douglas production function and concludes that fitting the function to a time series "has not yielded, and cannot yield, the statistical realization of a production function".

Solow (1960:90) too had his doubts and said “that it may be argued that the aggregate production function is itself a dubious tool”.

6.6. What does total factor productivity measure?

Prescott (1997) makes the case that a theory of TFP is needed. Prescott argues that TFP is the all-important factor to account for extremely large international income differences; whereas differences in physical and intangible capital (higher capital per worker), or differences in national savings cannot account for international income disparities. A theory of TFP should include additional factors, not only the growth in technical knowledge, to account for international income differences, so that a theory of TFP is needed. The author argues that society’s policy arrangements cause resistance to the adoption of new technologies and to the efficient use of existing technologies (Prescott 1997:33).

In an overview of the TFP literature (Lipsey & Carlaw 2001:3), three main interpretations emerge: (1) TFP measures the rate of technical change; (2) TFP measures “only the free lunches of technical change, which are mainly associated with externalities and scale effects”; and (3) TFP does not measure anything useful. Lipsey and Carlaw (2001: 4) ask what TFP measures and conclude that “TFP does not measure technological change”. There is, however, the implicit assumption that in the long run, technological change is extremely important as the main determinant of economic growth. The authors’ study is consistent with Prescott’s, but adds to the list of additional factors.

In a subsequent paper, Carlaw and Lipsey (2003) examined the relationship between productivity, technology and growth in a survey of the TFP literature and drew the same conclusion, that is, TFP is not a measure of technological change.

The methodological issues are vital critiques of the philosophical underpinnings of productivity measurement, but it appears from the responses to these critiques that they are not fatal. Productivity measurement is feasible and credible despite these objections. However, less philosophical and more technical issues are also under attack. The rest of this chapter looks at these issues.

6.7. The mismeasurement hypothesis

Several aspects of this are examined and it is reiterated that there is often an overlap between different explanations. It is possible that Solow could have had the mismeasurement hypothesis in mind (that the official statistics understate true productivity) when he observed that computers are everywhere except in the productivity statistics (Kettell 2001:248).

Webb (1998:47-50) provides a general summary of the pitfalls in the measurement of productivity. The following three issues are highlighted: (1) the level and rate of growth of productivity is understated, emanating from the difficulties encountered in estimating real output (which relates largely to the accuracy of the CPI and price deflators discussed elsewhere in this dissertation); (2) over short periods of time, productivity growth rates are extremely volatile, whereas over long periods productivity follows the business cycle in a predictable way, possibly creating the false impression that a new trend has emerged; and (3) disaggregating the economy into sectors can introduce additional errors into the calculations because it is difficult to accurately allocate input or output to particular sectors.

6.8. Measurement of quality change

Although there are several explanations of the productivity paradox, the main arguments focus on measurement issues. Because quality change is believed to be measured inaccurately in the official statistics, the productivity paradox of information technology is regarded as a statistical deception. In particular, it is argued that the output of the ICT industry is difficult to measure (see, for example, Baily & Gordon 1988) and actual quality improvements achieved in the computer hardware and software industries are not adequately captured, or not captured at all, in the NIPAs. The BLS, however, does make adjustments for quality change in the national accounts (see, for example, Dean & Harper 1988). However, these adjustments are biased according to the *Advisory commission to study the consumer price index* (1996:53-56), also known as the Boskin Commission, and other researchers.

The quality change bias is found to be particularly pronounced with computers, and actual quality improvements are greater than those captured in the official data.

The problem of new product bias is examined in conjunction with or as a component of the quality change bias (Advisory Commission … 1996:47). Improvements in product quality refer to characteristics such as greater durability and better energy efficiency, less need for repair, lighter and safer products, etc. (Advisory Commission … 1996:13). The new product bias refers to the failure to include new products, or the delay in the introduction of new products into the CPI (see Advisory Commission … 1996:56-57). For example, the personal computer was only introduced in the CPI in 1987 (Advisory Commission … 1996:56).

The mismeasurement of quality change can have an enormous impact on the standard of living. For example, Fogel (2004:9-10), in an extreme view, states that his own rough estimates show that taking into account more leisure time, better health care and education would increase the growth rate of per capita income from 2.0 to 3.6% per annum over the past century in the USA, greatly improving the average citizen's standard of living. Conventional growth measurements estimate real incomes to have risen sevenfold, whereas the adjusted measurements estimate incomes to have risen 34 times between 1900 and 2000. Consequently, Fogel (2004:10) reckons that “80 percent of the goods and services that Americans enjoy today are outside of the measured economy”.

Diewert and Fox (1999:274) argue that mismeasurement can explain the productivity paradox and, moreover, can account for the abrupt productivity growth collapse in the 1970s, for two main reasons:

> (1) the lack of adjustment for inflation in calculating business income, particularly during periods of high inflation when accounting of costs (such as interest and depreciation) can fail, leading to inaccurate product pricing and causing a loss of efficiency in the economy; and
>
> (2) the failure of traditional cost accounting, resulting in higher tax payments and lower productivity of an economy under conditions of high inflation and the current system of business income taxation.

Diewert and Fox (1999:252-263) also discuss other aspects of the mismeasurement hypothesis which can account for the slowdown, but *cannot* account for the abruptness of the slowdown in the 1970s. These are the measurement problems associated with the failure of the under-resourced statistical agencies to measure the costs and benefits of new goods and products; the misclassification of final demand as intermediate business expenditures; and the mismeasurement of services industries’ outputs. A subsequent paper by Diewert and Fox (2001) drew similar conclusions.

In contrast, Gilbert (1961:291) does not believe that quality improvements are measurable – hence quality improvements should be construed as an “unmeasurable benefit that is derived from cost-free progress in the arts of production”. Thus, *quality change should be reflected in the production index, not the price index* (Gilbert 1961:291) (italics added). The confusion is between enforcing either a price or a quantity change; for example, the introduction of a more compact motorcar does not mean deflation (lower price) – it means a decrease in the amount of production per motorcar (lower quantity). The consumer is demanding less output because his/her tastes have changed. According to Gilbert (1961:294), quality changes are like changes in taste: they cannot be captured by indexes. Indexes should not be concerned with the consumers’ level of satisfaction (Gilbert 1961:291). Consumer satisfaction is not a measurable concept.

According to Baumol et al. (1989:239-240), there is no need to explore the complex set of characteristics of a product to measure quality improvements, because the price mechanism (through relative price adjustments) is a transmitter of information about product characteristics and unambiguously conveys the product’s utility to the consumer.

The mismeasurement hypothesis is itself under attack. Baker (1998a) interprets some of the problems with this hypothesis. He argues that the costs of adopting new technologies are not generally incorporated in the CPI analysis. A far greater effort is made to assess the benefits, but little effort is made to quantify the costs of new technologies. For example, Baker (1998a:7) argues that it is an addition to the cost of living to own, say, a telephone, a computer or the internet (in order not to lag behind other users). A further example is that an improvement in the treatment of Aids (e.g. a longer life expectancy) cannot be accounted for as an improvement in the standard of living unless a downward adjustment in living standards was made at the onset of the pandemic (e.g. a shortened life expectancy).

In an early paper on services measurement, Hill (1977:333) denies that nonmarket services, such as some educational services for which output values have to be imputed, are more difficult to measure than manufactured goods. In fact he believes that mismeasurement problems are probably less severe in services than in some manufactured goods, particularly those undergoing rapid technological progress!

Similarly, the OECD (1991:8) study, *Technology and productivity: the challenge for economic policy,* concludes that "measurement errors can account for only a small share of the slowdown in productivity". Also, Pakko (2002) examines the high-tech (that is, information processing and communications technologies) investment boom and economic growth in the 1990s in terms of quality changes affecting the sector. He finds that quality adjustment in the various high-tech sectors affecting the measurement of investment in the NIPAs do not account for the rapid growth rates in investment rates in the 1990s, because variances of investment growth in some sectors overwhelm the actual investment growth rates (Pakko 2002:16).

Sichel (1997a:11) contends that despite the increased use of computers, it is unlikely that the mismeasurement gap has widened in recent decades. In terms of Gordon's earlier classification (see **table 6.1** above), Sichel does not believe that mismeasurement qualifies as an explanatory candidate.

6.9. Quality change and hedonic methods

Hedonic indexes were discussed in chapter 3. They are applied here to the issue of quality changes and measurement of productivity.

The BLS uses five methods to adjust for quality change for an existing product, several of which are biased (see Advisory Commission … 1996:53-56). To rectify these biases, hedonic indexes are the main tools for adjusting for quality changes in the national accounts. As stated in chapter 3, in 2001, hedonic techniques were applied to NIPA components which amounted to 22.3% of GDP. Hedonic methods have spawned a large body of literature and a brief overview is provided here. See for example, Triplett's (2004) *Handbook on hedonic indexes and quality adjustments in price indexes: special application to information technology products* and the US National Research Council (NRC 2002), *At what price? conceptualizing and measuring cost-of-living and price indexes*. Triplett is one of the leading experts and practitioners in price hedonics (Hulten 2003:6). The NRC (2002:122-146) also provides an excellent overview of hedonic methods (Hulten 2003:9).

Diewert and Fox (2005:3) find that the use of hedonic methods "has lead to substantial declines in investment deflators, relative to the unadjusted price indexes…. The lower deflators lead to higher real investment, and hence higher output levels. The more accelerated the fall in prices, the higher the rates of real GDP growth. This can, in turn, impact on productivity growth estimates."

Maddison and Denison, however, are two economists who regard hedonic methods with great suspicion, if not outright contempt. Maddison (2005:28-29, appendix 3) characterises the work by Nordhaus (1997a), a paper dealing with the application of hedonic methods to the history of the price of light from 1800 to 1992, and DeLong (1998), on the estimation of world GDP from one million BC to the present, as "hallucigenic history". Maddison (2005:4) believes that the over-use ("an overdose") of hedonic methods renders the national accounts chaotic; he remains sceptical that "quality changes have been so large and monotonically positive".

Denison (1989:15-38) critically examines the hedonic method developed for quality measurement of computers introduced and developed by Cole et al. (1986) and Cartright (1986) and adopted by the BEA. His comprehensive critique is further discussed below (see **sections 6.16 & 6.17**).

As long ago as 1961, Gilbert (1961: 287) stated that the quality adjustments that can be captured by index numbers are limited and therefore should be avoided, because "these challenges are conceptually wrong; they rest on the assumption that intangible quality improvements can be brought into the sphere of quantitative measurement. In the end, they would make it impossible to construct measures of output and price changes that are useful to the study of economic growth".

In a critical review of price hedonics, Hulten (2003:12) assesses the "pathology of the hedonic technique" and provides a brief summary of the hedonic method. He finds three general problems with hedonic regression models. The first problem is product differentiation: "where does a good stop being a variety of a given product class and become a product on its own" (Hulten 2003:9). The second refers to the selection of product characteristics: characteristics influencing producer as well as consumer behaviour should be included in the regression analysis, which unrealistically assumes that producers and consumers share the same set of product attributes. For example, consumers may value a motorcar's maximum speed and acceleration, whereas producers may value engine power and safety. Also, different consumers may not use the same set of product characteristics on which they base their spending decisions or value them differently. There are other problems as well (Hulten 2003:10). The third problem refers to the choice of functional form of the production function. Functional forms were discussed in chapter 2 and earlier in this chapter.

The multicollinearity problem (discussed above) rears its ugly head in hedonic techniques and has become a “red flag” against its use, although Triplett (2004: chapter VI) believes that the problem is not unmanageable if the data are thoroughly cleaned. Triplett’s *Handbook* (2004) also devotes chapter VII to objections to the hedonic indexes, in particular, to the view that hedonic indexes fall too fast.

According to the NRC (2002:140), hedonic regression techniques are therefore not a cure all for quality measurement problems because they do not capture increases in product variety or solve the problem of the introduction of new goods. The NRC (2002:140), however, states that “there is nothing better for dealing with certain aspects of the quality change problem”. Also, the NRC (2002:141) recommended that the BLS adopt “a more cautious integration of hedonically adjusted price change estimates into the CPI”.

6.10. Intangible capital

The quality measurement issue is related to the concept of intangibles, that is, intangible investment and intangible assets. There is now a growing interest in intangibles and this is reflected in more research papers being devoted to the issue (for a list see Corrado et al. 2006:2, footnote 2). Certain “intangible” factors, such as quality changes, are difficult to measure and capture in the indexes. The service sector in particular poses a measurement problem and a large body of research has been devoted to analysing the difficulty of measuring the output of the service sector (see Griliches 1992a; Guile & Quinn 1988; Hill 1977; Howitt 1998; Sherwood 1994). The services sector was discussed in chapter 5 and is elaborated on below.

The OECD’s manual (2001:93), defines “intangible fixed assets” as “non-financial produced fixed assets that consist of mineral exploration, computer software, entertainment, literary or artistic originals and other intangible fixed assets intended to be used for more than one year”. Nakamura (1999:3-4) classifies new product developments, copyrights, patents, new processes for making existing goods, brand names and trademarks as intangibles. These intangibles are typically the result of R&D investments. Corrado et al. (2006) provide a similar list of intangibles. Prescott (1997:4) includes human capital as an intangible. Because intangibles are not counted in the NIPAs, investment as well as national income and national saving are understated (Nakamura 1999:10).

Nakamura (1999) claims that intangibles “Put the *new* in the new economy”. In a subsequent study, Nakamura (2001) quantified the US gross investment in intangibles and found that it was (at least) one trillion dollars a year. This amount of intangible investment is almost on a par with investment in fixed nonresidential plant and equipment of $1.1 trillion in 2000 (Nakamura 2001:2). Similarly, Corrado et al. (2006) examined intangible capital and economic growth. In their study they found that from 2003 as much as $800 billion of intangible investment was still excluded from the published data, the inclusion of which would drastically alter the observed pattern of GDP growth. The authors conclude that if intangibles are counted as capital, the role of MFP in economic growth is reduced and capital deepening becomes the dominant cause of economic growth (Corrado et al. 2006: "abstract").

Only in 1999 did the BEA start to include software investment in the NIPAs, "so US measured gross domestic product is nearly 2 percent higher that it would be if intangibles weren't counted at all" (Nakamura 2001:2). As stated by Oliner et al. (2007:87) "The NIPAs omit production of virtually all intangible capital other than software."

According to Madrick (1998:55-58), Sichel's 1997 study finds that if software investment were included, computers would boost productivity by only 0.75% per year; and if computer depreciation were included, the productivity boost would be reduced to 0.15% per year.

Yang and Brynjolfsson (2001) rework the standard growth accounting methodology to include intangible computer investments. Computer-related investments form part of unmeasured intangible assets and the authors find that complementary (to computer hardware) but intangible computer investments are far larger than the direct investments in computers. They report that TFP in the USA grew as much as 1% per annum faster in the 1990s compared to the official estimates. They find that "computers are everywhere" when intangibles are included: "Even back in 1987, the years of Solow's famous quip, we estimate that computer hardware and its complementary intangible investments may have been equal to about 7.5% of GDP, if the 10 to 1 ratio … for a sample of 753 large firms held throughout the economy" (Yang & Brynjolfsson 2001:21).

An earlier paper also found a 10 to 1 ratio (Brynjolfsson & Yang 1999), which uses financial market valuations of firms to estimate intangible costs. (Their actual results are not reported in detail here because they regard the paper as preliminary and incomplete.)

Gordon (2004b:123) takes up the intangible problem but dismisses the 10 to 1 ratio as greatly exaggerated. He opines that hidden intangible capital is more likely to be reduced to a ratio of 1 to 1 if communications hardware is taken into account. Pertinently, Gordon argues that Yang and Brynjolfsson should explain why intangible capital did not produce a productivity growth revival during the 1972 to 1987 period, during which ICT investment rose rapidly. Solow referred to this in his famous quip (Gordon 2004b: 124).

6.11. Problems with index numbers

Because index numbers are the main tools for productivity analysis, this account of the productivity paradox has focused on index number theory and its application in practice. Sichel (1997a:91, footnote 33) remarks that whereas it is generally agreed that nominal output is well measured, “the problems lie in the price indexes used to translate nominal output to real output”.

Diewert (1987) provides a general overview of index numbers and his entry in The new Palgrave dictionary of economics commences with an account of the index number problem, thus showing its relevance. But just how controversial index numbers can be is shown in the opening quote in the preface to a standard text on index numbers by Allen 1975:ix): “Index numbers are a widespread disease of modern life … It is really questionable … whether we would be any worse off if the whole bag of tricks were scrapped. So many of these index numbers are so ancient and so out of date, so out of touch with reality, so devoid of practical value when they have been computed, that their regular calculation must be regarded as a widespread compulsion neurosis” (Moroney 1956:48-49).

In his popular tract, *Facts from figures,* Moroney (1956:50) cynically dismissed indexes as “academic tomfoolery of telling us what we already know from hard experience”.

Wynne and Sigalla (1996) provide a comprehensive survey of measurement biases in price indexes and the index number problems. A brief summary, based on their paper, is provided here (Wynne & Sigalla 1996: 56-58):

(1) The first set of problems arises with the measurement of the individual prices of the goods and services that comprise an overall price index. Several issues emerge:

  (a) Quality changes.

  (b) Measurement of services.

  (c) Measurement of the flow of services from a durable good, such as a house or a motorcar. See services below.

  (d) Representativity of sampled prices.

  (e) List prices versus actual prices.

(2) The second set of problems is how to aggregate individual prices of goods and services into a single measure of the overall price level. This is known as the index number problem.

The index number problem seriously affects the computation of the share of the computer industry in investment and the capital stock in the overall economy. Sichel (1997a:41) and Oliner and Sichel (1994:278) argue that nominal rather than real magnitudes are appropriate for calculating these variables, since “these real shares … have little meaning and can be made to take on almost any value depending on the base year chosen” (Sichel 1997a:41).

The use of hedonic methods and chain indexes involves two methods of approaching the problem. Neither solutions are fully satisfactory and have been criticised in the literature, particularly hedonic methods.

Generally, index numbers, for all their sophistication, are blunt instruments and may fail to adequately capture the true values of the variables they measure. As standards of measurement, index numbers could fall short of the ideal and could be inaccurate – despite the sophistication of methodology and econometric tools – and should be used with caution.

6.12. Factor income shares

Factor income shares were discussed in chapters 2 and 5. The measurement of factor income shares is also considered controversial and difficult to pin down precisely. Generally, researchers have estimated the proportion to be between 70 and 75% for labour and 30 and 25% for capital.

A key property of the Cobb-Douglas function is the behaviour of factor income shares, because “in a competitive economy … capital and labour are each paid their marginal products; that is, the marginal product of capital equals the rental price … and the marginal product of labour equals the wage rate” (Barro & Sala-i-Martin 2004:30). According to Cornwall (1987:661), the justifications for the weighting scheme in the Cobb-Douglas production function are neither convincing nor well-defended, and what type of bias could result has not been clarified. The values chosen for weights are based on the share of output or income accruing to the primary factor inputs, capital and labour, in any particular country. Although factor shares do measure each input’s contribution under perfect competition, the real world does not conform to perfect competition, irrespective of equilibrium conditions (Cornwall 1987:661). Indeed, perfect competition is a necessary assumption for the marginal productivity theory of distribution to account for the share of income (Pearce 1992:10).

Prescott (1997:11-12), however, states that there is a constancy of factor income shares over time and across countries and that the income share of labour does not vary with income levels, and has fluctuated at around 70%. For most countries, labour shares are in the range of 0.65 to 0.80. Thus factor shares are approximately constant across time and space.

Cornwall’s article (1987:661) in *The new Palgrave: a dictionary of economics* highlights several of the weighting scheme concerns: “the justification of the weighing schemes in growth accounting have never been convincing nor have they been well defended”. Because the weighting scheme of capital and labour is flawed, in that it assumes constant returns to scale, several important issues emerge:

(1) It reduced the share of capital to insignificance thus highlighting the unimportance of capital for economic growth. This view is reflected in the work of Denison (1980a:220), which concluded that "capital is *one* of *several* important sources of output growth … capital is not *the* source of growth" (italics in original).

(2) There were concerns about the unusually large size of the residual, which indicated that there was something amiss with the analysis, irrespective of whether the residual was referred to as efficiency, technical progress or TFP.

(3) If scale economies are introduced as an explanatory variable (to explain the residual) constant returns to scale are violated.

(4) There may be interactions between the factor inputs and TFP and it might be impossible to separate such inputs, especially capital, from the components of the residual.

Romer (1987:165) argues in favour of increasing returns to scale and finds that the "conventional growth accounting analysis substantially underestimates the role of capital accumulation in growth. The correct weight on the rate of growth of capital … may be closer to 1 than to 0.25." Over the long run, labour's exponent of 0.1 to 0.2 is smaller than its share of income (Romer 1987:166). Labour's trivial share, if interpreted literally, implies that output is almost independent of labour input (Bernanke 1987:204), which seems to be an absurd conclusion.

Sarel (1997) argues that the calculation of factor shares is crucial to the accuracy of the relative contribution of accumulation versus TFP. He provides an alternative method to the national accounts and regression approaches for calculating factor shares. His results contradict previous studies of growth and productivity in Singapore, Thailand, Malaysia, Indonesia and the Philippines. The precise determination of factor income shares is therefore crucial. As mentioned in chapter 2, Senhadji (2000:152) and Sarel (1997:14) have shown that TFP's contribution to output is highly sensitive to the share of capital: a higher share of capital implies a lower contribution of TFP to growth.

6.13. ICT and the services sector

Many economists have argued that the output of the services sector is particularly difficult to measure. Significant ICT investment has gone into service industries, which are the most intensive users of ICT (Bosworth & Triplett 2003:2).

As discussed in chapter 5, Griliches (1994) divides total output into the "measurable" and "unmeasurable" sectors. The "unmeasurable" industries, largely the service industries, grew as a share of GDP between 1947 and 1990. Since over three-quarters of computer investment had been in the "unmeasurable" sectors, the productivity effects were "largely invisible" (Griliches

1994:11). Griliches believes that this explains the computer productivity paradox. More specifically, he (1994: 3) imagined a “degrees of measurability” scale with a dividing line between measurable and unmeasurable sectors in GNP. Measurable sectors are agriculture, mining, manufacturing, transportation, communications and public utilities, whereas the unmeasurable sectors are construction, trade, finance, other services, and government (Griliches 1994:3, note to figure 1). Between 1947 and 1990, the measurable sectors’ shares dwindled from 48.7 to 30.9% of GNP, implying that the unmeasurable sectors had risen from about one-half (51.3%) to above two-thirds (69.1%) (Griliches 1994:11, table 2). Measurement problems have therefore worsened and along with it the ability to interpret total factor productivity (Griliches 1994:10). Indeed, Griliches (1994:11) argues that

> the consequence of this shift is what has become known as the “computer paradox.” We have made major investments in computers and in other information-processing equipment. … Why has this not translated itself into visible productivity growth? The major answer to the puzzle is very simple: over three-quarters of this investment has gone into our “unmeasurable” sectors…and thus its productivity effects, which are likely to be quite real, are largely invisible in the data.

The fact that services output is difficult to measure is also argued by Sherwood (1994), Diewert and Fox (1999:262-263) and McGuckin and Stiroh (2000).

According to Roach (2003), in the services sector, both the productivity numerator (or services output) and the denominator (hours worked) are inaccurate. Output measurement (the numerator) is “hopelessly vague for services” and official measures are inaccurate because they have used worker compensation as a proxy for output in many service industries. White-collar productivity is overstated since working hours (the denominator) have become longer (owing to modern communication technology), whereas the official average work week has been unchanged since 1988 at 35.5 hours.

Output mismeasurement is discussed more fully in the next section.

6.14. Mismeasurement of output

Both output and input can be subject to mismeasurement. Brynjolfsson (1993) argues that mismeasurement of output is largely the inability to calculate accurate quality-adjusted price deflators. Sichel (1997a:90) contends that output is intangible and hard to measure. He (1997a:90-100) discusses several aspects of output mismeasurement: (1) mismeasurement and neoclassical contribution to growth; (2) the Boskin Commission report and the measurement gap; (3) mismeasurement and final demand; and (4) whether mismeasurement has increased over time. The first issue was discussed above, while the Boskin report is dealt with below.

Gilbert (1961:288) contends that, in essence, an increase in output means that “all the goods of the base year are available (with quality unchanged) plus additional units of some goods. The additional units constitute the increase in output”. Hence “economic welfare as a measurable idea must be restricted to telling us if we are better off only by our having more goods. Any broader idea of welfare which would take account of the character of the goods available, or the satisfaction they give, may be a perfectly valid subject for speculative appraisal, but it is not measurable” (Gilbert 1961:288).

6.15. Neoclassical framework

Sichel (1997a:91), in his seminal work, points out that computer output mismeasurement or unmeasured output will have little effect on the contribution of computers to **output growth** in the neoclassical framework. This is so because “the estimates of computing services’ contribution to output growth were derived from the input side *and do not rely on estimates of real output growth* … the neoclassical contribution to output is calculated from capital and labour inputs that generate computing services, along with assumed rates of return for these inputs. Thus mismeasurement of output would not affect *neoclassical* contributions to growth” (italics in original) (Sichel 1997a:91).

Sichel (1997:93)also states the following:

> an assertion that the neoclassical contribution to output growth is too low because some of the output generated by computers is not measured is essentially an assertion that computer hardware and software earn supernormal returns.…Unless one is prepared to assert that computer hardware or software earned supernormal returns, mismeasurement of output growth will have little impact on the size of the neoclassical contribution of computing services to output growth.

Similarly, Sichel (1997b) argues that mismeasurement problems of industry **output shares** are related to the method of calculating aggregate GDP. Sichel’s (1997b:368, footnote 5) argument is worth quoting in full:

> Strictly speaking, output shares should be based on a final product decomposition, rather than an industry decomposition. The Bureau of Economic Analysis (BEA) obtains its official measure of aggregate GDP by adding up expenditures on final products, corresponding to the familiar income accounting formula Y = C + I + G + X - M. Once this total is obtained, the industry output figures are derived by dividing up this total. As

pointed out forcefully by Denison (1989)[2] and Baily and Gordon (1988), *undermeasurement of one industry's output does not imply that total output is undermeasured because the total has already been fixed. Rather, undermeasurement of one industry's output within this already fixed total implies that output in some other industry is overmeasured (italics added).* For this reason, final product shares are more appropriate for an analysis of mismeasurement of aggregate output. Having said that, it turns out that the growth in the measurement gap owing to a share shift appears similar using either set of shares.

6.16. Intermediate products

As mentioned in the above quote by Sichel, according to Denison (1989:60-64), productivity studies by industry (used in the NIPAs and by the BLS and BEA) as opposed to productivity studies by final or end product are problematic and plagued with statistical problems as well as conceptual ambiguities. Statistical problems refer to the lack of accurate data, data gaps and inconsistencies and biases introduced by indexes (Denison 1989:61-62), as discussed in chapter 3.

To recap, many services are not final products. Intermediate goods or products are used during the production process of other goods rather than for final consumption (Pearce 1992:211). Final goods are used for consumption purposes (Pearce 1992:152). A clear distinction needs to be drawn between "service industries and final products that are services … they are enormously different" (Denison 1989:60).

Thus, according to Denison (1989:13-4 & 60), services accounts for only 33% of output if classified in terms of final product, whereas the SNO shows a 59% contribution. More particularly, conceptual problems are threefold with intermediate products: (1), productivity increases show up in the using industries; (2) productivity originates in a third industry; and (3) productivity shows up in no industry at all.

Firstly, in the presence of intermediate products, productivity increases emerge in the industries that use the improved products and not in the industry that generates the productivity improvements. Intermediate products are raw materials, supplies, containers, business services, structures and equipment. Denison (1989:62) states that "If the product is intermediate, the

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[2] "Output valued in constant prices in the business sector as a whole is estimated by deflating the final-product components of the sector's gross national product. No use is made of data for industries. The output of the sector as a whole is divided among industries. … Thus estimates of output by industry in no way affect the business sector's total output" (Denison 1989:7).

productivity increase appears instead in the industry that consumes the better product and thereby reduces costs."

Triplett (1999a:5-6) echoes this argument in stating that most output of the computer-using industries is intermediate output, not final output, such as in business services and the wholesale trade. Aggregate productivity measurement applies to final demand categories, which complicates productivity analysis.

Secondly, Denison (1989:63) states the following: "Many advances in knowledge that raise productivity originate in neither the producing nor the using industry but in some third industry from which technology is transferred. Or they may not originate in any industry within the business sector, but instead in an inventor's garage, a government or college office or laboratory, someone's home, or another country. … most improvements have many parents."

Thirdly, "some changes in the productivity of a business sector appear in no industry at all if the data are accurate" (Denison 1989:63). Examples are the gain from improved allocation of resources among industries (a shift of excess labour out of low-productivity farming into high-productivity industries, thus raising productivity in the whole economy) and increased specialisation among industries (when the market size increases) (Denison 1989:13 & 63). However, process innovation and managerial improvements show up in an industry's own productivity (Denison 1989: 13 & 63).

Finally, Denison (1989:64) remarks on the pervasiveness of the productivity slowdown that "the productivity slowdown appeared in almost all major industries in almost all industrial countries after 1973" so that industry productivity allocation is not of great concern in this regard.

6.17. Gross versus net measures of output

There is disagreement on whether gross or net output should be used as a measure of output, that is, GDP versus NDP, or GNP versus NNP. This question is relevant to the productivity paradox debate because ICT and computers typically depreciate at a faster rate that other types of capital. Equipment and software have increasingly shorter life cycles which means that the rate of depreciation is high. Spending on depreciation replaces worn-out or obsolete equipment and software, and hence does not add to the economy's productive capacity. The usefulness of gross measures of output has therefore declined (Spant 2003:39-42).

Also, according to Diewert and Fox (2005:2): "There is a strong case for greater focus on this thorny issue in light of the 'new economy', or the economic environment that has been created by the large increase in the use of computers and information technology in the last couple of decades". These authors also consider two depreciation models which can be used as extremes or "bounds" for other models in the light of different countries adopting different depreciation methods in their national accounts (Diewert & Fox 2005:7-12). Whelan's (2000:1) study of computer productivity introduces a new method for calculating computer depreciation (technological obsolescence) and uses computer capital stock with embodied technological change. Although "computers are not everywhere", computer capital stock is more ubiquitous than estimated in Sichel's seminal 1997 study. This study (Sichel 1997a:10) found that computers make up only about 2% of the USA capital stock, and therefore constitute a small share of the inputs used to produce output. The main reason for the small share is the rapid rate of depreciation and obsolescence of computer stock.

Similarly, Diewert and Fox (2005:1) believe that "economists (and accountants) have long thought that the correct measure of output for many purposes is net output, as this takes into account the consumption of capital, or the decline in the efficiency of the available capital stock".

The divergence between gross and net output measures is a recent phenomenon which did not exist between 1947 and 1973 (see **table 6.3** below). The rising investment in computers and software caused this divergence (Baker & Rosnick 2007:4).

However, according to Diewert and Fox (2005:2), depreciation methods are problematic and different methods yield different depreciation rates: "The problem of how to best calculate depreciation has been a long-standing one…. The best solution to this problem is unclear and this has lead to different national statistical agencies employing different methods."

Hulten, in two related papers (1992a & 1992c) and Denison (1989) interrogate this problem. Hulten (2000:7-8) argues that the consumer-welfare interpretation of productivity is a perennial concern in the interpretation of productivity and net measurements are preferred to gross measurements. This issue has "introduced a fundamental ambiguity about the nature of the total productivity index", which, according to Hulten (2000:8), is evident even today.

Denison (1989), a growth accounting pioneer, makes the case that net output must be used – in fact his entire productivity analysis is based on net output. Denison employs NNP, or national income, rather than GDP. He prefers a net product measure, because society's goal of enjoying a large output can best be achieved through maximising output net of capital consumption, since it is pointless to maximise the quantity of capital goods used up in production (Denison 1989:6).

Denison (1989:9) also points out that there are flaws in the BLS methodology, since the additional output generated by better computers is counted twice in GDP: the production of computers is counted in the computer manufacturing industry, and the use of computers in computer-using industries. However, net national product counts the additional output generated by computers only once and in computer manufacturing industries. In computer-using industries, the rapid depreciation of computers offsets any quality adjustments, thus preventing computers from increasing productivity.

Denison (1989:21) estimates that the effect of exceptional computer productivity on computer output and thus on output per hour is different, depending on the use of NNP per hour rather than GNP per hour: the growth rate of NNP is about 67% of that of GNP of the nonresidential business sector. He concludes that because of depreciation, computers cannot raise productivity in the computer-using sectors.

Spant (2003: 41) makes a similar case and points out that in a country like the USA, where investment in ICT has increased as a portion of total investment, capital depreciation has grown faster than GDP. As a consequence, a widening gap has emerged between GDP and NDP growth rates (Spant 2003:41). Spant (2003:42) – see **table 6.2** – calculates that for the USA, real GDP growth was 0.28 percentage points higher (3.42 minus 2.93) than real NDP between 1995 and 2001; and depreciation as a percentage of GDP was 2.45 percentage points higher (14.03 minus 11.58) in 2001 compared to 1995. Similar trends can be seen in other OECD countries, but to a lesser extent: gross and net measures of domestic product diverge by 0.15 percentage points; and depreciation by 0.75 percentage points on average.

Table 6.2: GDP and NDP growth and depreciation in 16 OECD countries

	Compound annual average growth rates 1995-2001		**Real depreciation as a percentage of real GDP**	
	Real GDP	**Real NDP**	**1995**	**2001**
OECD*	3.06	2.91	13.86	14.60
USA	3.42	2.93	11.58	14.03

Source: Spant (2003:42, table 1), based on OECD data. Note: * Unweighted average of 16 OECD countries, including the USA

Baker (2002:120) provides similar calculations (**table 6.3**), based on BLS data, and demonstrates the difference between gross and net measures of productivity in the USA in recent years. **Table 6.3** shows that after 1979, gross and net measures of productivity growth rates started to diverge, which broadly coincides with the productivity decline in the 1970s. Baker also argues in favour of net measures and contends that productivity growth of 2.5% per annum in the "new economy" period between 1995 and 2000 is possibly too high because a greater share of output is allocated to replace old plant and equipment (Baker 2002:118): "Output used to replace worn-out equipment (depreciation), while a necessary cost, is not increasing the nation's consumption or increasing its ability to produce goods and services in the future".

This problem relates to the embodiment controversy discussed in chapter 2. Embodied technical progress implies that new or more recent vintages of capital equipment (or computers) are more productive, or should potentially be more productive, than equipment of older vintages. In a nutshell, new capital is better than old capital (Greenwood & Jovanovic 2000:2).

Table 6.3: US productivity growth (% annual average rates)

Period	Published data	Estimated net measure
1949-59	2.8	2.8
1959-69	2.8	2.8
1969-79	1.9	1.9
1979-89	1.4	1.2
1989-2000	1.9	1.7
1995-2000	2.5	2.1

Source: Baker (2002: 120, table 1)

The case of software reclassification is illustrative. Chapter 4 discussed the impact of the 1999 change in the NIPA methodology to reclassify software as investment rather than as an intermediate input. The reclassification increased total nominal investment by about $95 billion in the private sector and by $20 billion in the public sector, thus increasing nominal and real GDP by around 1.5% in 1999. However, NDP was little changed because depreciation rose equally. According to Spant (2003:41), the reclassification also caused the gap between GDP and NDP to widen, weakening the former's significance as a measure of general welfare.

Spant (2003:43) concludes that "the implications of placing almost all emphasis on GDP and neglecting NDP is to overestimate: the real rate of economic growth; productivity increases; the potential for increasing wages without inflationary risks to the labour market; gross business profits, thus increasing the risk of stock market bubbles; and differences in growth rates between countries (e.g. between the United States and Europe)".

As mentioned above, according to Madrick (1998:55-58), Sichel's (1997a) study finds that if software investment is included, computers would boost productivity by only 0.75% per annum; and if computer depreciation is included, the productivity boost is reduced to 0.15% per annum.

In a related concern, Hulten (1992c) asks whether productivity measures capacity or welfare. He concludes that gross product is the correct concept to measure the structure of production, and that net output is appropriate for measuring the welfare consequences of economic growth.

6.18. Mismeasurement of input

It is possible that input may also be mismeasured. Roach (1998a:156 & 158), for example, has made the claim that some inputs are understated. He argues that labour input is understated because people are in fact working longer hours, which is unmeasured, leading to an overstatement of productivity growth.

Computer input, that is, the stock of ICT, can also be mismeasured. Denison (1989:24-32) addresses the issue of computer capital and measurement problems and finds that capital goods, including computer capital, can be measured only with great difficulty. Denison (1989:25-32 & 1993) describes four methods to quantify quality changes of capital goods: (1) capital measured by cost; (2) capital input proportional to total output; (3) capital measured by marginal products; and (4) capital measured by consumption foregone.

Denison (1989:9) contends that all direct and indirect labour and other inputs should be counted in computer models. The BEA's measures of computers are flawed because the measured computer product doubles when a new computer's output is double that of an old model, ignoring the labour and other inputs in the new model even if these are much higher or lower.

6.19. Primal versus dual measures

Hsieh, in various papers (1999, 2002), analyses the East Asian growth miracle. He disagrees with Young (1995), who found that factor accumulation played a fundamental role, whereas TFP played an insignificant role, in the East Asian growth miracle. A brief discussion is included here because of its importance to productivity growth generally rather than computer productivity specifically. This problem relates to the productivity paradox in the measurement problem context.

Hsieh (2002:519) highlights the difficulties involved in constructing reliable national accounts and capital stock data and calculates productivity using the dual rather than the primal method. The dual is regarded as a complementary method to the primal method (Hsieh 1999:237). Hsieh (1999:138) concludes, particularly in the case of Singapore, that technology can be shown to have played a greater role in economic transformation when productivity measures are based on the dual rather than the primal measure.

Fernald and Neiman (2003:3-5) provide a succinct summary of how the primal and dual calculations are arrived at (see also Aiyar & Dalgaard 2005:84-85). Primal TFP measures are based on *quantities* and dual TFP measures on *prices* (Fernald & Neiman 2003:1). In principle, these measures should give the same result, but in practice they may differ (Fernald & Neiman 2003:4).

Overall, the equivalence of the primal and dual measures is a significant conclusion and shows that productivity can be measured in terms of both quantities and prices. This could help to overcome data problems in the national accounts, as was the case of the East Asian growth miracle debated by Hsieh (1999, 2002) and Young (1995).

6.20. Inflation and the understatement of productivity

Measurement of inflation and price indexes play a key role in the productivity paradox.

The idea of the overstatement of the CPI (or an upward bias) goes back to at least Gilbert's 1961 paper, *Quality changes and index numbers*. As Gilbert (1961:287) states, we are concerned with the fact that if a rise in price is overstated, then a rise in real output is understated. Thus productivity could also be understated. The US price statistics were also under official scrutiny in 1961 by the Stigler Commission (Boskin et al. 1998: 4). Subsequently, the *Advisory commission to study the consumer price index*, also known as the Boskin Commission study, published in 1996, investigated the calculation of consumer price inflation data (Advisory Commission … 1996). The commission's members are all eminent economists: Michael Boskin (Chairman), Ellen Dulberger, Zvi Griliches, Robert Gordon and Dale Jorgenson. The study was followed by additional publications and responses to criticisms to the study by the commission (see Boskin et al. 1997, 1998).

The Boskin study found that several factors influence the measurement of inflation and reduce its accuracy. The factors are: (1) the substitution bias; (2) the retail outlet bias; (3) the quality bias and the new goods bias; and (4) the formula bias. In general, quality improvements account for the bulk of the overstatement. The commission's study concluded that, because price indexes do not account accurately for these factors, the CPI was overstated by an average (or suffered from an upward bias) of about 1.1 percentage points per annum over an extended period. Generally, the study found that the CPI does not adequately reflect the changes in the cost of living. Since the productivity growth rate is a real variable (nominal output is deflated by an appropriate price index, the inflation rate, to arrive at a real productivity growth rate), real output, and hence productivity growth, should be higher than stated in the official data. The focus has been on the accuracy of the price deflator (CPI), rather than the adjustment to nominal output or inputs.

The commissions' results are summarised in **table 6.4**.

Table 6.4: Boskin Commission estimates of biases in CPI		
Source of bias	**Contribution**	
	Percentage points per annum	Percent
Upper and lower level substitution	0.4	36.4
New outlets	0.1	9.1
New products/Quality change	0.6	54.5
Total	1.1	100.0
Plausible range	0.80 – 1.60	
Source: Boskin et al. (1996): Table 3 (no page numbers)		

The commission's study elicited a number of responses. The *Monthly Labor Review* published three articles on "Prices and productivity measures" by Eldridge (1999), Gullickson & Harper (1999) and Dean (1999) in February 1999. In particular, Moulton (1996), who is the Chief, Division of Price Index Number Research at the BLS, examined the evidence of CPI bias. Moulton and Moses (1997) also review the Boskin Commission's report.

In an insightful article, Baker (1996:26), discovers flaws in the Boskin Commission's arguments and points out that consumer price indexes are essential for "nearly every economic calculation that involves historical comparisons" and that adjustment of the historical inflation rates "will change nearly everything we thought about the economy"! Put simply, Baker (1998c) believes that "the new economy does not lurk in the statistical discrepancy".

Baker (1996:28) argues that if the findings are correct, "economists have been promulgating a great deal of nonsense over the last fifty years". In particular, if the inflation rate is overstated or biased upward, the commission's result implies that if real incomes or wages are recalculated backwards or reconstructed to the early 1950s – which is a period of post-war affluence (Krugman 1998:190) – most of the typical American families were living below the 1994 poverty line. Similarly, future generations could look forward to far greater prosperity than previously, because real wages will grow at a faster rate. In essence, Baker provides a *reductio ad absurdum* of the commission's report. He (1998a:7-8) also believes that the commission only focused on areas of possible overstatement, ignoring the new and additional costs that new technologies impose on consumers, but incorporating the gains. Madrick (1998:58) adopts a similar view and points out that mismeasurement could also be in the opposite direction: a fall in quality could also be mismeasured, such as in retail services and airline travel. Baker (1996:33) concludes by noting that "there is not much work in economics that will be left standing" if the report's findings are accepted.

Eldridge (1999) examines the effects of price indexes on productivity measures in detail and provides a considered assessment of the Boskin Commission's study. Eldridge concedes that the current indexes (as at 1999) do have biases and that the BLS and BEA are aware of these problems.

Moreover, according to the BLS economists, the Boskin study itself contains several faults (Eldridge 1999:39). Therefore the Boskin Commission's study is not the final say on the CPI controversy. The commission does not claim that the CPI is overstated now more than it was in the past (Baker 1998c:6). Hence, the overstatement of inflation argument cannot be advanced to resolve the productivity paradox.

6.21. Conclusion

This chapter reviewed the main explanations of the productivity paradox from the philosophical and methodological approach to the more specific and technical aspects. At many levels of explanation, problems of meaning and interpretation were found and flaws in methodology encountered. The philosophical objections dealt mainly with the neoclassical paradigm, which has long been under attack by economists, who have pointed out the unrealistic assumptions upon which this paradigm is built. The construction and interpretation of the Cobb-Douglas production function also came under scrutiny and were criticised accordingly.

The measurement of productivity in official statistics, through the construction of index numbers (as is the case with many economic time series), forms the central area of investigation, because this information is used in many productivity studies and is reported in the financial media. Economic historians and cliometricians typically use figures produced by the official agencies to analyse economic trends. Macroeconomic analysts rely on the historical data to study macroeconomic trends and provide forecasts. Also, policymakers, especially central bankers, such as the Federal Reserve, base their analyses and judgements on official productivity data.

Therefore an understanding of the purpose, function and limitations of economic indexes, especially price indexes, clarifies many issues relating to the productivity paradox, because they affect productivity measures directly. For example, the Boskin Commission, whose research can be taken as the most comprehensive in this regard, did not conclude that the mismeasurement of CPI has increased over time or that there are breaks in inflation trends, only that there is a general overstatement of the CPI over time.

The measurement of quality change is not a new phenomenon, nor confined to computers, because many indexes do not account adequately for quality improvements in a number of products and services. Some authors believe that the available indexes are accurate enough, but others contend that measurement error can explain the productivity paradox.

Shortcomings and inaccuracies have been discovered in the national accounts, which are the subject of on-going debate. Most of the important issues are discussed in this chapter. The USA statistical agencies, the BEA and BLS, however, are alert and receptive to academic research and often make adjustments and improvements to the official data when the evidence of mismeasurement is convincing. Other issues also have a bearing on the measurement of productivity, such as the net versus gross output debate as well as alternative ways of calculating productivity (e.g. primal versus dual measures).

Several authors have doubted the veracity of the mismeasurement hypothesis. Some of the arguments put forward are that computers comprise such a small a share of total inputs that they cannot impact significantly on output, even if they were substantially undermeasured; since computers are generally used as intermediate inputs, so that the final-demand share of computers in difficult-to-measure services output, is small; and the measurement gap has not widened since the widespread use of computers in recent decades.

For some economists, the paradox has been resolved and was a mere statistical discrepancy and artefact, but for others, the new economy does not lurk in the statistical discrepancy.

7. CHAPTER 7: OTHER EXPLANATIONS OF THE PRODUCTIVITY PARADOX

7.1. Overview

Following the previous chapter's theme, other explanations of the computer paradox are examined in this chapter. The general purpose technology hypothesis is investigated first. Secondary explanations are the mismanagement, input substitution and the sceptical hypotheses.

Whereas there are several explanations of the *productivity slowdown*, such as the oil price shock in the 1970s, only those hypotheses that relate to the *Solow productivity paradox* are examined here .

Some of the explanations that have been postulated to explain the productivity slowdown are briefly mentioned.

7.2. The general purpose technology hypothesis

The general purpose technology or time lag hypothesis states that the productivity benefits from IT investment are still forthcoming because there is a lag between IT spending and the ultimate realisation of productivity benefits. The reason for the time or diffusion lag is that IT is a general purpose technology (GPT) which takes many years or even decades to affect output and productivity positively. This view is based on historical observations of other GPTs. The inventions of steam power and electricity are the prime examples of earlier types of GPTs, and ICT and computerisation are of a more current vintage. Other technologies such as the internal combustion engine and railways are also mentioned in the GPT literature.

According to David and Wright (1999:10), GPTs share the following four characteristics: the technologies can be improved and expanded over a wide range of applications; they have many different and varied applications and uses; they have the potential application for use in an array of products and processes; and they can form complementarities with existing or potential new technologies.

Old GPTs such as the steam engine, the electric motor (also electricity, electrification, etc.) as well as new GPTs, such as semiconductors, function as "enabling technologies", opening up new opportunities through potentially pervasive use in a broad range of industries. Although GPTs do not provide ultimate solutions they can generate productivity gains throughout the wider economy (Bresnahan & Trajtenberg 1995:84).

David's (1990) short but seminal paper, *The dynamo and the computer: an historical perspective on the modern productivity paradox* views the productivity paradox from a historical perspective and discusses various characteristics of *general purpose engines*, David's terms for GPTs. David mentions the steam engine but selects the electric dynamo as an example of a general purpose engine. David (1990:346) compares the slow adoption and diffusion of the electric dynamo and the lagged effects on industrial productivity, with computerisation and productivity lags, for the following reasons: “Computer and dynamo each form the nodal elements of physically distributed (transmission) networks. Both occupy key positions in a web of strongly complementary technical relationships that give rise to ‘network externality effects’ of various kinds.”

Adoption of GPTs is often slow, that is, there are “diffusion lags”, because of the long learning curve, consumer inertia and resistance to abandon older and more expensive technologies.

David’s (1991) more comprehensive paper *Computer and Dynamo: The Modern Productivity Paradox in a Not-too-Distant Mirror*, which is included in a collection of papers on the productivity paradox published by the OECD, expands on his 1990 paper. David responds to economists who are perplexed by the “contemporary conjunction of rapid technological innovation and disappointingly slow gains in measured productivity”. He (1991:322) stresses that drawing parallels and finding resemblances (“We see the dynamos everywhere but in the productivity statistics”) between the dynamo and computer have their limitations and must not be taken too literally. Although David (1990: 360; 1991: 336) states that “Computers are not dynamos”, he suggests that there are parallels: namely “pervasive diffusion”, “incremental improvement” and “confluence with complementary technologies” over a long time frame (David 1991:315).

Around 1900, industrial countries started to experience a technological transition from a reliance on steam to electricity. The productivity benefits of electrification of industrial processes did not fully emerge until 40 years after about half of factory capacity had been electrified (David 1991:335-336).

Helpman and Trajtenberg (1994) developed a growth model based on successive new generations of GPTs, characterised by recurrent cycles over the long run. The initial impact of a new and more productive GPT is to lower output (Helpman & Trajtenberg 1994:2). The new GPTs also give rise to repetitive cycles. Each cycle consists of two distinct phases: in the first phase, output and productivity growth slows or declines, real wages stagnate and the rate of profit declines, whereas in the second phase, growth starts to take off, wages rise and profits recover. The authors (1994:2) conclude: “Over the entire cycle the economy grows at the rate determined by the rate of advance in the GPT itself.”

Thus productivity does not necessarily rise significantly during periods of rapid technological progress. This counter-intuitive notion is demonstrated by the slow rise in productivity during the Industrial Revolution (Crafts 2002:3; Trehan 2003:1). The full effects of technological revolutions are often evident only several decades after their invention and introduction. These technological revolutions are typically supported by GPTs. For example, Crafts (2002:21) re-examines productivity growth during the Industrial Revolution, using a revised growth accounting methodology, and calculates the sources of growth estimates during this period to back up this claim (**table 7.1**).

Table 7.1: Accounting for growth during the British Industrial Revolution				
% per year		**Contributions from**		
Period	**Output growth**	**Capital Stock Growth**	**Labour Force Growth**	**TFP**
1760-1780	0.6	0.25	0.35	0.0
1780-1831	1.7	0.60	0.80	0.3
1831-1873	2.4	0.90	0.75	0.75
Source: Crafts (2002:21, table 1)				

In his approach to the problem, Crafts (2002:19) takes account of the embodiment of technological change in new varieties of capital goods. He finds that in the early years of the invention of a GPT there is little productivity growth. The issue of disembodied and embodied technical change was discussed in chapter 2. Essentially, what needs to be reconciled is the "slow macroeconomic TFP growth with spectacularly successful microeconomic innovations in several important industrial sectors" (Crafts 2002:3). For example, in the case of electricity, Crafts (2002:4) observes the following: "While the excitement of the electrical age arrived in the 1880s, the main (very substantial) productivity impact came only in the 1920s when the possibilities for re-design of the factory were realized."

Using the dual technique based on factor prices, Antràs and Voth (2003), also investigate productivity growth during the British Industrial Revolution (1770-1860) and find that it was slow during this period, thus reinforcing Crafts's primal method, based on quantities. The dual method is complementary to the primal method as discussed in chapter 6.

Jacobs and Nahuis (2002:244) argue that GPTs can explain the Solow paradox. They contend that computerisation causes a slowdown in output growth, because highly skilled workers temporarily spend their time accumulating new knowledge and thus neglect current production.

The GPT theory has its opponents. Roach (1998a:159-160), for example, disagrees with the GPT theory, calling it "the fallacy of historical precedent". He argues that there are vast differences between the tangible-goods (i.e. factory-based) production of the Industrial Revolution and the intangible knowledge creation of the services-based ICT information age.

Similarly, Gordon (2000b:64-5) asserts that diminishing returns in computers do not support David's analysis and have already eroded any ICT productivity gains. Diminishing returns were discussed in chapter 5. Furthermore, contrary to the GPT hypothesis, Gordon argues that "it is more plausible that the main productivity gains of computers have already been achieved"! The reason is that some industries, such as airlines, banks and insurance companies, rapidly adopted mainframe computers - as early as the 1960s and 1970s - and that computers have accordingly already provided benefits for almost 50 years.

Stiroh (2001a:48) echoes this interpretation and argues that the "critical mass and delay hypothesis is beginning to lose credibility" because computers can no longer be viewed as new investments given that the first commercial purchase of a mainframe computer, the UNIVAC, was in 1954, and computer investment already appears in the national accounts in 1958.

Moreover, Gordon (1999b:127) argues that earlier inventions were "more fundamental creators of productivity than the electronic/internet era of today". Computers do not compare to the great inventions of the past, which historically boosted productivity growth. The earlier inventions are broadly classified into four clusters: the electricity cluster, which includes electric motors, the electric light and consumer appliances; the internal combustion engine cluster, which includes motor and air transport, superhighways, supermarkets and suburbs; the rearrangement of molecules clusters, which include petrochemicals, plastics and pharmaceuticals; and the communications/entertainment cluster, which includes the telephone, radio, movies and television (Gordon 1999:127).

Madrick (1998:52) also criticises David's 1990 paper, arguing that David does not take into account many other factors that contributed to the significance of electricity, from assembly-line mass production techniques to useful home appliances, such as washing machines and radios, which could account for as much of the output growth as electricity itself.

Some authors have argued that ICT was itself responsible for the slowdown in productivity through the slow and costly learning, implementation and diffusion process. Greenwood and Yorukoglu (1997), Greenwood (1997) and Greenwood and Jovanovic (2000) examine the problems associated with the adoption of a new technology such as steam, electricity and ICT. Greenwood (1997) and Greenwood and Yorukoglu (1997) ask whether the year 1974 was a watershed, ushering in a new (third) Industrial Revolution. However, because inexperience of new technologies led to inefficiencies and lower productivity growth, rapid technological advancement is associated with slow productivity growth. Greenwood and Jovanovic (2000), discussing post-war economic growth in the USA, postulate that there was a slowdown in productivity growth because it is costly and slow to implement information technologies. Huggett and Ospina (2001) also find that productivity falls after the adoption of new technology during a period of technology-specific learning, because some expertise can fail to transfer from the old to the new technologies.

Kiley (1999:1) also contends that ICT itself was responsible for the slowdown. Computers, particularly the PC, are still relatively new and the various investment adjustment or transition costs of “incorporating the new technology into business practice are substantial”. These large adjustment costs, such as reorganising plant layout, managerial costs, work interruptions, worker training and on-the-job-learning, lowered growth in MFP by some 25% from 1974 to 1991. Kiley (1999:15) concludes that the contribution of the ICT revolution to output growth in the last few decades has been mostly negative through a combination of high adjustment costs and the surge of computer investment.

Hornstein and Krusell (1996) also argue that technology improvements themselves can cause productivity slowdowns. This means that a “transition to a new technological regime can actually slow productivity growth as firms take time to learn how to use the new technology”. This period of “learning-by-doing” is one of the more intriguing explanations why productivity improvements are postponed (Sumo 2006:31).

7.3. The mismanagement hypothesis

This hypothesis states that companies typically underestimate the full costs of new information technology and consequently misallocate technology resources (Stolarick 1999). Dempsey et al. (1998:137) summarise the view well: “Once a cost centre, IT is now at the core of many businesses. It can be a source of competitive advantage if managed well, a liability if managed badly.”

Many business journals such as the *Harvard Business Review* and *McKinsey Quarterly* (Cho & Neiman 2002; Dempsey et al. 1998; Olazabal 2002) discuss issues relating to the management of ICT. For example, IT failures are not widely reported, perhaps because companies are loath to be seen to have made mistakes. Carr (2004:110-111) cites some examples of IT projects that failed, based on a 1995 study:

> Of more than eight thousand systems projects … examined, only 16% were considered successes – completed on time and on budget and fulfilling the original specifications. Nearly a third were cancelled outright, and the remainder all went over budget, off schedule, and out-of-spec. Large companies – those with more than $500 million in annual sales – did even worse than the average: Only 9 percent of their IT projects succeeded.

The above quote is from Carr’s (2004) book, which rhetorically asks *Does IT matter?* The book is based on his controversial 2003 article, published in the *Harvard Business Review,* in which Carr contends that IT has become an infrastructure resource. He argues that IT has become a homogenised commodity, which means that it has become “essential to competition but inconsequential to strategy” (Carr 2004:108).

Business success is generally linked to its business model rather than its technology. Based on several studies by reputable research companies, Carr (2004) concludes that there is no correlation between IT spending and business performance. Much IT expenditure by businesses is wasted, particularly on personal computers. He also argues that companies that excel at IT, excel more in other aspects of running a business, such as in strategy. Examples are Wal-Mart (a US retailer) and Dell (a US computer company) (Carr 2004:87-129). Investment in IT has also not led to higher profits (Carr 2003:49).

In distinguishing these related hypotheses, the mismanagement hypothesis blames management rather than IT as such, whereas both the GPT and the sceptical hypotheses blame computers themselves.

7.4. Computerisation and input substitution

This interpretation states that the computer paradox is solved by interpreting computerisation as an input substitution event and not as an MFP event. This view emphasises a type of sectoral approach (i.e. computer-producing versus computer-using sectors) instead of the aggregate approach, as well as a production function approach. The interpretation of MFP in terms of production function shifts was discussed in chapter 2, while the aggregate and sectoral approaches were dealt with in chapter 5.

The differential in MFP performance between the computer-producing and computer-using sectors is discussed in **section 5.7** on the economics of ICT. To recap, researchers found MFP gains in the *manufacture* of computers (computer-producing sector), but little MFP improvement in their *use* (computer-using sector). The rapid decline in the price of computers (see chapter 5) has led firms to invest more in computers and less in other labour and non-computing inputs and investments. This did not raise MFP, but increased computer accumulation (Stiroh 1998:176) – hence, the conclusion that “the economic impact of the computer is not a productivity story at all” (Triplett 1999b:314)!

Stiroh (1998) also argues that the computer revolution is largely characterised by input substitution, investment and capital accumulation. This argument states that the computer revolution is characterised by input substitution, not MFP growth. Computers are both “an output from one sector and an input to other sectors” (Stiroh 1998:175). In the computer-producing sector, MFP has been high, and the production function has shifted, which implies MFP growth. In contrast, the computer-using sector, has not experienced MFP growth, and there are thus movements along the production function, rather than a shift of the function. An aggregation approach is therefore avoided in favour of the disaggregated sectoral approach.

7.5. The sceptical hypothesis

The sceptical (or pessimistic) hypothesis states that computers are simply not productive and that this is a real phenomenon rather than a paradox in need of an explanation.

According to the Canadian Centre for the Study of Living Standards publication, *Productivity: key to economic success* (CSLS 1998:33-35), the benefits of IT are exaggerated and there are several good reasons why computers are unproductive. The first is that IT investment makes up only a small share of total economy-wide investment. However, if a distinction is made between IT's share in nominal (current dollar) and real (constant dollar) terms, the picture changes. (This issue was discussed in chapter 6 and the mismeasurement hypothesis.) The second reason is that IT does not fundamentally change the production process; nor does it improve the quality of decision making. The third reason is that IT costs are understated; if the actual costs were calculated, IT's productivity benefits would be significantly lower. The costs associated with the "Y2K bug" are a case in point, as well as the many international virus attacks on government, business and other computer networks, which can paralyse e-mail systems, destroy databases, install spy-ware and disrupt internet and other business services.

The problems associated with ICT, particularly PCs, have reached comic proportions in the view of some users. For example, Triplett (1999b:324) quotes a cartoon character, Dilbert, who comments that "the total time that humans have waited for Web pagers to load … cancels out all the gains of the information age". Another humorous example is the exchange between General Motors and Microsoft, "If GM were like Microsoft ", which is reproduced in the appendix to this chapter.

Triplett (1999b:324-326), in a more serious vein, lists several objections to the idea that computers improve productivity. The rapid pace of technological progress and the concomitant rapid obsolescence and scrapping of hardware have led to the replacement of hardware before being worn out. Yet these massive investments into state-of-the-art technology in the past period show no return in the present period. This applies to both software and hardware. Costs of upgrading are rarely considered and could be wasteful. The addition of new or enhanced features to a faster upgraded computer may result in poorer performance compared to an older PC with fewer and less flashy features, leading to the quip: "What Intel giveth, Microsoft taketh away" (i.e. so-called "bloatware", a play on the word software). Time costs during change-overs are also rarely accounted for.

Computers have many detractors and there are numerous articles confirming this. Jorgenson and Stiroh (1999:110) disparagingly refer to the rising IT investment as "a kind of Computer Cargo Cult among economists and economic historians, patiently awaiting a deluge of spillovers like those that supposedly accompanied earlier technological revolutions".

Even researchers working in the computer industry are sceptical. As Michael Dertouzos, a Director of MIT Laboratory for Computer Science since 1973, explains in a magazine interview (Bielski 2001:50):

> I've been complaining for years that computers are wonderful but infantile. … They're hard to interact with, and they don't often give us information we can use. Take the internet. … It is little more than a virtual society of exhibitionists and voyeurs. The companies are the exhibitionists – bragging about who they are and what they have. The surfers are the voyeurs. And sprinkled intermittently in this "brew" is a small percentage of the world's commerce, about $200 billion or 1% of the world's economy. We can do much more with the technology.

Landauer (1995:75), in *The Trouble with Computers*, succinctly sums up the productivity paradox in the context of the services sector by stating the following: "IT made it possible to do more work but not to do work more productively. … The total new output from services just about equalled the total new input in IT equipment and the labour hours it required."

In essence IT enabled more work to be done at the same productivity level (Landauer 1995:76).

Bowen (1986) argued there has been a "puny payoff from office computers" because productivity was no higher in the 1980s compared to the 1960s, despite businesses spending hundreds of billions of dollars on office computers. Bowen argues that managers are still learning how to use them.

Krugman (1998:102-103), always an insightful iconoclast, wrote as follows:

> the startling thing about computers is not how fast and small they have become but how stupid they remain … Even where computers have become ubiquitous … it is very questionable how much they actually raise productivity. Recently many companies have begun to realize that when they equip their office workers with computers they also impose huge hidden costs on themselves – because a computer requires technical support, frequent purchases of new software, repeated retraining of employees, and so on. That $2,000 computer on your employer's desk may well impose $8,000 a year in such hidden costs".

Stephen Roach (1998a:158), a well-known computer sceptic, points out the huge costs associated with the Year 2000 bug or Y2K, "a prime example of the deadweight of the information age.". According to Lawson (2006:14), the Y2K bug, otherwise known as the Millennium Bug, was an “illusory infection…In 1999, billions were spent on prophylactic treatment for an imaginary condition. In the Western world, only the Italian government took the decision not to listen to the dire warnings from self-interested software companies (almost all of them American). And, as we know, not a single Italian-owned computer went down coughing and spluttering with the Millennium Bug.“

Roach (1991:85) wrote that the massive investments in IT have not improved productivity in the services sector but instead made service firms less profitable and even less competitive.

Economic studies generated similar results. Morrison and Berndt (1991) found that in 1986, at the industry level, marginal costs of high-tech IT equipment exceed marginal benefits which implies an overinvestment in IT capital. Berndt, Morrison and Rosenblum (1992) found a negative correlation between labour productivity growth and investing in high-tech equipment (as a ratio to total capital stock) between 1968 and 1986 at industry level.

Madrick (1998: 52) argues that many computers enthusiasts’ opinions are “not so much hardheaded analyses as expressions of faith, almost religious in nature, which often sarcastically chide those who resist the message of true believers”. Progress is regarded as linear; thus assuming that today’s innovations will have the same impact as yesterday’s (Madrick 1998:53). Madrick (1998:54) also contends that much of the enormous computer power is superfluous because the ease of obtaining and processing information may be easier, but quality of output is not necessarily better; for example economic forecasting has not improved simply because calculations are faster (Madrick 1998:54). He claims that modern computing technology has not made a large impact on efficiency as is generally assumed.

7.6. Explanations of the productivity slowdown

The various interpretations of the productivity slowdown (which is a vast and interesting topic), which do not relate specifically to computerisation and the ICT sector’s possible role in the apparent slowdown have not been examined here. It would be useful to make brief mention of these factors for conceptual clarification.

Factors that have been postulated to explain the productivity slowdown are as follows: the energy crisis in the 1970s; the exhaustion of the technological boom; low investment and savings; high taxation of savings; excessive government regulation; low public investment in infrastructures; the decline of investment in research and development; sociological explanations, such as the increasing laziness of the workforce; and the decline in quality of education, and other factors (Krugman 1994a).

Gordon (1999b:123) is convinced that explanations that rely on a single cause of the productivity slowdown are incomplete. It seems that the productivity slowdown cannot be pinned down by a single cause. Therefore, it is unlikely that ICT was the single cause of the slowdown.

7.7. Solow's later responses to the computer productivity paradox

It is worth considering some of Solow's remarks and comments on his eponymous statement of the computer paradox, that "computers are everywhere but in the productivity statistics" (Solow 1987:36), as a prelude to the conclusion. It was this remark that sparked the line of research known as the productivity paradox of information technology – indeed a "Quip that launched a thousand production functions" (Kraemer & Dedrick 2001 2). The views expressed by Solow on the computer paradox are briefly reviewed here.

Solow's quip appeared in a review of Cohen and Zysman's book *Manufacturing matters: the myth of the post-industrial society* (1987) published in the *New York review of books*. They contend that manufacturing is at the heart of the modern economy and that the notion of the post-industrial society – where services reign supreme – is misplaced and incorrect. Cohen and Zysman (1987) argue that many service activities are closely linked to manufacturing and a loss of manufacturing activities will result directly in a loss of these service activities.

The following year, Solow (1998:120), in his review of Sichel's book *The computer revolution*, argued that the stock of computer capital (including software) is simply too small a fraction of overall fixed capital stock to make a difference to productivity. Solow (1998:121) also believed that "the role of the computer appears to be a paradox only because many people expect too much. Sheer technical innovation may be mind-boggling, but GDP does not respond to boggle".

In March 2000, in a *New York Times* interview, Solow stated the following: "You can now see computers in the productivity statistics", but added that "I will feel better about the endurance of the productivity improvement after it survives its first recession" (Uchitelle 2000:4). Solow's retraction is in response to Oliner and Sichel's 2000 paper analysing the recovery of the productivity growth rate in 1995.

Subsequently, in a 2002 interview, Solow, in response to the productivity revival from 1995 to 2000, stated the following (Clement 2002):

> Now what would it mean to resolve the paradox? It could mean that eventually productivity responded, that at last we do see computers in the productivity statistics. That is possible and, in fact, even likely. Why should all that technology not affect productivity? Even now, however, we don't have the complete story.

In retrospect, we know that the period from around 1970 to 1995 – a whole quarter of a century – was a time of extremely slow productivity growth, and that is the period during which the computer was really penetrating our society. … but it's not a clear certainty, that some or all of that acceleration of productivity is the computer at last bearing fruit.

Then Solow argued as follows (Clement 2002):

… th*ere does not appear to be a miracle in productivity terms that we can attribute to the computer* (italics added). Comparing the computer with electricity or the internal combustion engine just doesn't seem to me to be justified yet. … there's also some respectable evidence that within the service sector, gains or accelerations in productivity are not much correlated with improved computer use. … So I think that the outcome is still unresolved. … the paradox has dissipated in part. I don't think that we fully understand the answers yet.

The above quote therefore affirms that, in Solow's opinion, computers are not as productive as generally believed and that the story is unresolved. Solow's comments are of a recent enough vintage relative to the productivity revival in 1995 to have incorporated the recent productivity statistics.

7.8. Counterfactual research: the world without computers

A full understanding of the computer paradox still needs to be written. The methodology may well be to study the counterfactual proposition: "what productivity growth would have been without computers" to discover the true impact of computers (McGuckin & Stiroh 1998:45). This approach – the so-called "new economic history" or cliometrics – is certainly not new in economics, but generally unknown (even in the economics profession) despite the Nobel Prize for Economics having been awarded to Robert Fogel in 1993 (shared with Douglass North) for "research in economic history by applying economic theory and quantitative methods studies" (Nobel Prize 1993). Computers have often been compared to the railroads as the *sine qua non* for modern economic growth.

Fogel (1962 & 1966) examined the economic impact of railways – known as the "railroad revolution" because of its perceived central role as the main driver of economic growth after 1840 in the USA – based on counterfactual arguments. Fogel concluded – counter-intuitively – that the invention and installation of railroads had quite a *small* impact on economic growth in the USA. He analysed what economic growth would have been without railroads, or what growth would have been if the same resources had been invested in alternative (but existing) industries (Fogel 1966:16), thus challenging the notion that railways were indispensable for US economic growth (Ferguson 1999:17). The growth impact is small because railroad transport has several transport substitutes. Thus the economy would have been only slightly smaller without railways in

1890 (Ferguson 1999:17). Fogel (1966:40) found that railroads increased the economy's productive potential only by about 3% of GDP.

7.9. Conclusion

This and the previous chapters showed that many economic factors have been found to impact on the Solow computer paradox. In this chapter, three more explanations and hypotheses were reviewed, in addition to those reviewed in chapter 6.

The general purpose technology argument is intuitively appealing and appears to be borne out by historical events. The explanation, however, is not watertight, because ICT cannot be compared in the same way to steam or electricity since they are different types of entities, as pointed out earlier. However, the economics of GPTs does shed light on the Solow paradox as the passage of time plays a key role in technology diffusion.

Computers themselves are accused of being the culprits, in that the adoption of new ICT innovations is not an instant and costless process, but its success depends on several factors, particularly human capital and organisational capacity.

The mismanagement hypothesis explores the many expensive failures to implement and manage complex computer systems properly in organisations as a possible explanation of the Solow paradox. As reported above, less than one-tenth of ICT projects are successful, an appalling record for an industry that is acclaimed by insiders to be a driver of productivity.

The input substitution hypothesis denies that computerisation is a productivity story. According to this hypothesis, the real story is the substitution of cheap computer capital for other more expensive forms of capital, as well as for labour.

The sceptical view forks into two areas. There are some researchers - and even industry insiders - who cannot abide the new computer age and resort to ridicule. Although some observations are anecdotal and therefore not quantifiable, there is a grain of truth in many of the computer-related jokes and anecdotes. Others believe that the actual costs of computerisation have not been included properly into the calculations.

Solow' own pronouncements on the later developments were reviewed. Solow does not believe that there is a productivity miracle as yet, despite high expectations, and that the computer paradox remains unresolved.

Counterfactual research on the computer paradox, if ever attempted, could shed new light on the complex issue.

In the next and final chapter, the conclusion is drawn that it is unlikely that a unified theory can be found that will be able to fully explain the complexity of the Solow computer paradox.

7.10. Appendix - “If General Motors were like Microsoft” (2004)

If General Motors Were Like Microsoft.

At a recent computer expo (COMDEX), Bill Gates reportedly compared the computer industry with the auto industry and stated: "If GM had kept up with technology like the computer industry has, we would be driving twenty-five dollar cars that got 1000 miles to the gallon."

In response to Bill's comments, GM issued a press release stating (by Mr. Welch himself):

If GM had developed technology like Microsoft, we would be driving cars with the following characteristics:

1. For no reason whatsoever your car would crash twice a day.

2. Every time they repainted the lines on the road you would have to buy a new car.

3. Occasionally your car would die on the freeway for no reason, and you would just accept this, restart and drive on.

4. Occasionally, executing a manoeuvre such as a left turn, would cause your car to shut down and refuse to restart, in which case you would have to reinstall the engine.

5. Only one person at a time could use the car, unless you bought "Car95" or "CarNT." But then you have would have to buy more seats.

6. Macintosh would make a car that was powered by the sun, reliable, five times as fast, and twice as easy to drive, but would only run on five percent of the roads.

7. The oil, water temperature and alternator warning lights would be replaced by a single "general car default" warning light.

8. New seats would force everyone to have the same size butt.

9. The airbag system would say "Are you sure?" before going off.

10. Occasionally for no reason whatsoever, your car would lock you out and refuse to let you in until you simultaneously lifted the door handle, turned the key, and grab hold of the radio antenna.

11. GM would require all car buyers to also purchase a deluxe set of Rand McNally road maps (now a GM subsidiary), even though they neither need them nor want them. Attempting to delete this option would immediately cause the car's performance to diminish by 50% or more. Moreover, GM would become a target for investigation by the Justice Department.

12. Every time GM introduced a new model car buyers would have to learn how to drive all over again because none of the controls would operate in the same manner as the old car.

13. You'd press the "start" button to shut off the engine.

8. CHAPTER 8: CONCLUSION

8.1. Overview

Many economists concur that in the long run, productivity matters greatly for improving a country's living standards. The productivity paradox has therefore provoked considerable interest, not only because of the widespread use of computers, computer networks and the internet in government, business and private spheres, but also because of the substantial investments that the ICT sector has absorbed in recent decades. The productivity paradox, as stated by Solow (1987:36), questions the widely held belief that the widespread use of computers has increased productivity and hence the standard of living. Solow's responses to the evolving productivity debate are discussed to shed light on the robustness of his earlier views. Solow did not dramatically amend his subsequent views from his original formulation.

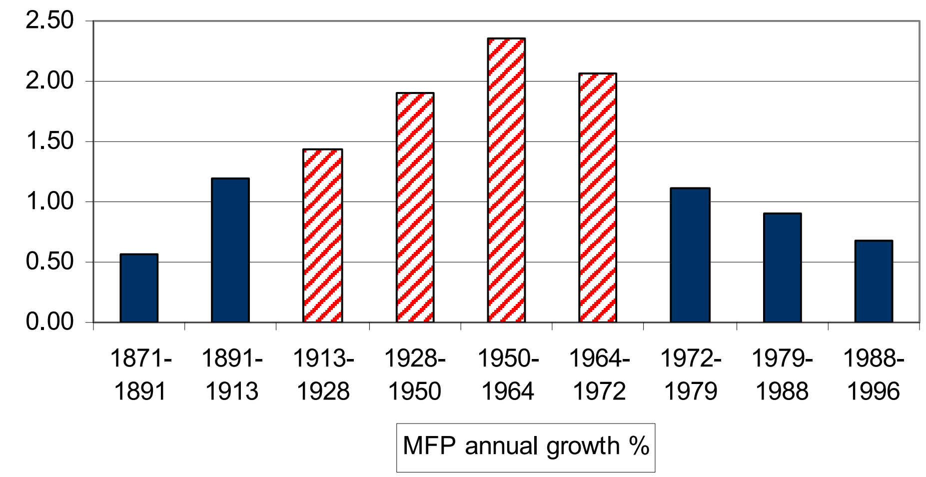
This chapter reviews the multilayered complexity of the Solow paradox and the conclusions from previous chapters are reviewed and evaluated accordingly. The Solow productivity paradox focuses on the period between 1973 and 1995, but productivity trends before 1973 and after 1995 are briefly explored to give a broader historical context of the paradox. The modern computer has a timeline dating back to the invention of the transistor in 1947 and the launch of the first IBM PC in 1981. Although the Solow paradox remains largely unresolved, counter-factual research (which is based on the so-called "new economic history" or cliometrics, the application of econometric techniques to economic history) may be a useful avenue for future research.

8.2. Productivity trends before 1973 and after 1995

Gordon (1999b:123) argues that the relatively lower productivity growth rates before 1913 and after 1972 should perhaps be regarded as normal trends; and the "glorious" 60 year period of high productivity growth from 1913 to 1972 (shown in red/diagonal shading), preceding the Solow paradox period, should rather be regarded as exceptional and atypical, and which thus requires explanation.

Gordon (1999b) describes productivity growth from 1871 to 1996 as "one big wave", which is confirmed by a visual inspection of the data and shows the sudden decline in 1972 (**figure 8.1**). Hence, in Gordon's view, there is therefore nothing exceptional in the productivity slowdown after 1973. Similar data are shown in chapter 1, from Arnold and Dennis (1999:10).

Figure 8.1: Long-run MFP trends: Gordon's "one big wave"



Source: Gordon (1999b:124, table 1)

Furthermore, according to Bosworth and Triplett (2003:1), a new productivity paradox has emerged since 1995: "The post-1973 puzzle was never resolved, just abandoned by economists when they were confronted with a new problem – the acceleration of U.S. productivity after about 1995."

In a recent paper by Oliner et al. (2007), ICT and the productivity revival are reviewed extensively, but there is no mention of the computer productivity paradox. It is simply no longer discussed.

The productivity revival after 1995 appears to have put the matter to rest. The respected London-based *Economist* newspaper declared that the '"productivity paradox" has been solved' (Paradox lost 2003:13).

Similarly, Gordon (2004b) found that there are now five new puzzles after the 1995 productivity revival. The puzzles are: (1) the cyclical versus the trend effect after the revival; (2) the productivity acceleration after 2000 when the ICT investment boom collapsed; (3) the key innovations that caused the revival; (4) the revival of ICT investment; and (5) the failure of Europe to experience a productivity growth revival (Gordon 2004b:118). In particular, Gordon asks why there was a growth acceleration after 2000 when the ICT investment boom collapsed? **Figure 8.2** clearly shows the investment collapse (an "investment strike") after 2000.

Gordon's key question is why the initial impact of computers on productivity growth slowed from the 1970s to 1995, a period marked by a continuous stream of significant innovations and the introduction of the first commercial computer in 1951 (Gordon 2004b:119 & 124). The period from

1995 to 2002 is informative, because the big box retail trade sector generated most of the productivity advances. Big box retailers are large US supermarkets such as Wal-Mart, Home Depot and Best Buy. According to Rogoff (2006), the importance, but paradoxical nature, of the services sector is illustrated by the “stunning fact” that Wal-Mart and other big box retailers generated about half of the productivity gains. Gordon (2004b:126) believes that the productivity improvements did not result from ICT investment per se, but from organisational and managerial advancements, such as ”large size, economies of scale, efficient design … and large scale purchases”.

According to Gordon (2004b:127), the surge in ICT investment from 1996 to 2000 and the collapse in 2001 and 2002 can be explained by five factors. These are: (1) the invention of the World Wide Web (WWW), which stimulated investment as companies developed internet web sites, investment which is not repeated as the WWW can be invented only once; (2) the negative return earned by many start-up internet companies resulted in these “dot.com” firms going bankrupt; (3) new memory-intensive business software packages necessitated new and upgraded hardware purchases to run them, but subsequent advances in hardware capacity did provide adequate memory capacity; (4) the Y2K crises prompted a once-off and early replacement of computer equipment and software; and (5) the communications sector was deregulated in 1996, leading to overinvestment and spare capacity in fibre-optic communications infrastructure.

These various developments reveal the complexity of productivity analysis in the context of the computer paradox.

8.3. The study of the Solow computer paradox

This section discusses the salient points from previous chapters which shed light on the Solow computer paradox. It is not intended to provide a complete summary of all the arguments put forward. The bibliographic references of the arguments presented in earlier chapters will not be repeated here.

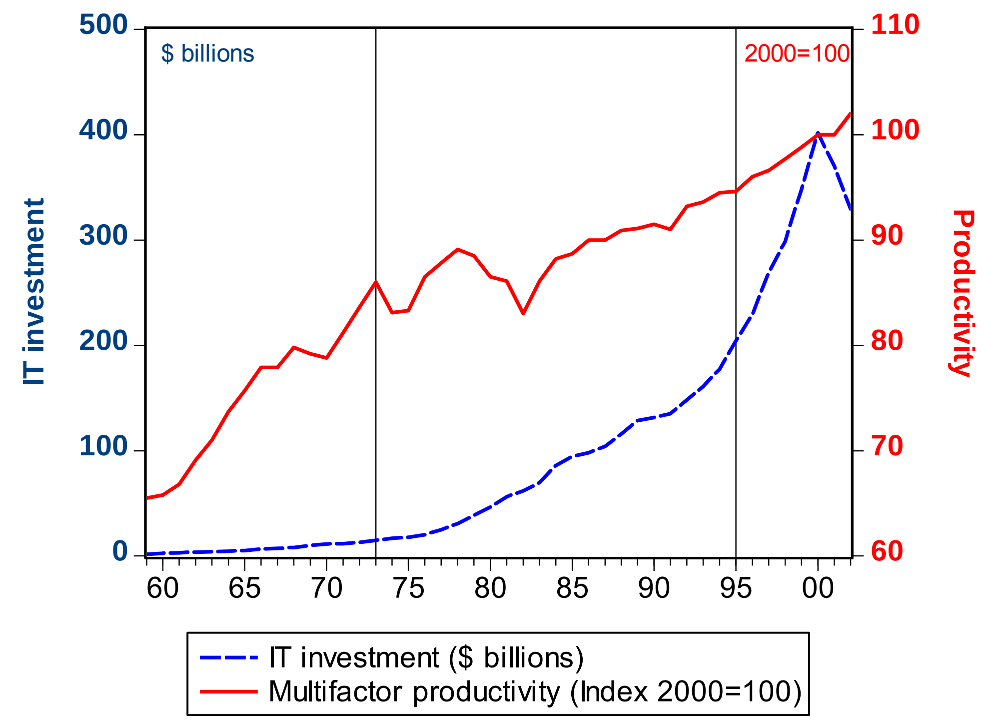
The Solow computer paradox literature has endeavoured to explain the phenomenon of rapidly rising IT investment but moderating productivity growth, particularly between 1973 and 1995. The computer revolution is evident in the IT investment data, which surged, but not the MFP data, which hardly responded.

Why would private individuals, businesses and organisations spend billions of dollars on ICT investments if there were no productivity payoff, as efficiency gains are some of the most important expected benefits and payoffs?

A visual inspection of **figure 8.2** illustrates the main features of the Solow computer paradox. The figure plots IT investment against MFP growth. Labour productivity shows a similar trend. MFP is plotted because Solow had multifactor productivity rather than labour productivity in mind, according to Triplett (1999b:328, footnote 5). The two vertical lines mark the structural break years of 1973 and 1995. Actual data for these graphs are given in the NIPAs, discussed in chapter 4. In particular, see **figure 4.4** for MFP growth trends over the three periods.

It should be kept in mind that the USA experienced a recession in 2001. According to the Business Cycle Dating Committee of the National Bureau of Economic Research (NBER), US economic activity reached a peak in March 2001, followed by a trough in November 2001. The latter date marked the end of the short recession and the start of an economic expansion. In 2000 the US stock markets also fell dramatically, especially the IT- and new economy-heavy NASDAQ composite stock index. Although MFP is procyclical, that is, it can be expected to grow more slowly, or to fall during a recession, and to rise steeply during a recovery (Fernald & Ramnath 2004:53), the sharp and sudden IT investment collapse follows a period of over 40 years of uninterrupted and rising investment in IT.

Figure 8.2: Productivity growth trends and IT investment from 1959 to 2002 and the Solow computer paradox



Source: US NIPAs

8.4. Productivity and technical change

In order to understand the Solow productivity paradox, the general framework and methodological assumptions are discussed in chapter 2. The historical and current foundation of productivity analysis rests on several neoclassical assumptions, a growth accounting framework and the aggregate production function, and more specifically, the widely used Cobb-Douglas production function. Many of these components have been challenged from dissenting philosophical and methodological positions, which tend to weaken, but not reverse, the subsequent results.

Neoclassical theory generally holds that capital accumulation dominates productivity as a source of growth; this tenet is referred to as "capital fundamentalism". However, because diminishing returns to capital set in over time, productivity is the main cause of long-run economic growth. Denison (1980a:220), in his short paper *Contribution of capital to economic growth* argues that capital should not be regarded as the prime source of growth, but that there are *many* determinants of output and growth. Even earlier, Salter (1960:1) argued that "behind productivity lie all the dynamic forces of economic life: technical progress, accumulation, enterprise, and the institutional pattern of society. These are areas where our understanding remains rudimentary".

The different classifications and interpretations of technical progress and the associated embodiment controversy reveal the complexity of how technical progress affects economic growth. The basic disagreement is whether or not technical progress requires capital accumulation and investment.

8.5. Productivity measurement

The next building block of the analysis and its statistical and econometric underpinnings are the use of index numbers, which also present a number of theoretical and practical problems. This is reviewed in chapter 3. The index number problem remains central to the understanding of the computer paradox because the correct construction and interpretation of index numbers determined the accuracy of many important economic time series (such as GDP, CPI, etc.) upon which many economic and econometric analyses are based. According to Dean et al. (1995:28-29), the development of several measurement techniques, while not perfect, can provide an acceptable solution to the index number problem.

Index number bias applies in particular to the potential distortion of measuring quality change and computer output inaccurately. This is because computer prices have been falling rapidly and continuously since the 1970s, whereas by comparison, the prices of most other goods have changed moderately.

8.6. Official data

The productivity statistics, as captured and calculated by the US agencies in the NIPAs, were reviewed in chapter 4. This formed the point of departure for much of the debate about the computer paradox, as many researchers criticise the BLS's and BEA's statistics and provide their own estimates.

There is a ongoing interaction between the agencies and academic researchers to refine and improve the national accounts and productivity statistics. Agencies frequently publish papers in accredited academic journals, which address issues raised by economists in these same journals. Many researchers revise official data in the light of their own models and the BLS and the BEA also revise the official data – these are the main reasons why precise figures and dates are sometimes difficult to pin down. Sometimes the data and dates are not identical; they do, however, reveal the same overall trends.

Productivity is an omnibus term that captures the interrelationship between output and the factors of production – land, capital, labour and entrepreneurship – as well as many other factors that influence the trajectory of output growth. In many instances, these factors are discussed separately and unrelated to their actual effects on output. The NIPAs are to "blame" because they capture what has been required historically rather than what is needed for productivity analysis.

Broadly speaking, there are two strands of opinion: the first claims that the NIPAs are largely correct and that there are sound economic explanations of the paradox; the second claims that the NIPAs are mostly wrong as the impact of ICT specifically and the services sectors generally are not captured accurately in the official data. Researchers in the latter camp have tried to disprove the computer paradox and to build models that establish the links between computers and productivity (Kraemer & Dedrick 2001:3).

However, tampering with the inflation and productivity statistics as published in the national accounts would render these accounts chaotic – as argued by Baker (1996:26-28) in his review of the Boskin Commission's (Advisory Commission …1996) findings that US inflation was overstated by 1.1% over a long period. This was discussed in chapter 6.

The NIPAs and their methodological building blocks provide a coherent picture, albeit grounded on several contestable foundations, as argued in Chapter 6.

8.7. Economic aspects of ICT

Chapter 5 reviewed the many economic aspects of ICT, mainly for conceptual clarification. A timeline of computing history illustrates the rapid development of computing since the 1950s; and the operation of Moore's law on the steep decline of semiconductor prices, a problem that is central to the measurement of computerisation in the national accounts. The “three faces of IT value” can be found in raised productivity (theory of production); greater business performance or profitability (theories of competitive strategy); and improved consumer value (theory of consumer), but computerisation is only related to the first value and should not be confused with the other two values, as it often is. A basic growth accounting framework is set out which incorporates ICT and non-ICT capital. Software, as a component of ICT capital, was incorporated into the NIPAs only in 1999. Computer-producing and computer-using industries are examined to see whether there are spillover effects from the former to the latter. Diminishing returns to ICT investment may already have set in, which implies that productivity gains from computers are now a thing of the past.

Declining computer (including software) prices – referring to hedonically adjusted computer prices, not what consumers actually pay in shops – have spurred large investment expenditures in ICT equipment since 1960. The hedonic method is used to estimate the effects of quality changes on prices by separating quality changes from price changes. Declines in computer prices are largely supply-side driven, and these have led to the substitution of ICT equipment for more expensive forms of capital and labour. This represents a movement along the production function, not a shift of the function, implying that there is no technical change.

The so-called “new economy” and the internet are based on the computer revolution and its take-off coincides to some extent with the productivity resurgence in 1995. Opinion is divided on whether the internet has ushered in a frictionless economy in which inflation will vanish and business cycles will disappear (Shiller 2005:119). The question has been posed whether the “new economy” measures up to the great historical inventions of the past, such as the steam engine and electric motor (David 1990).

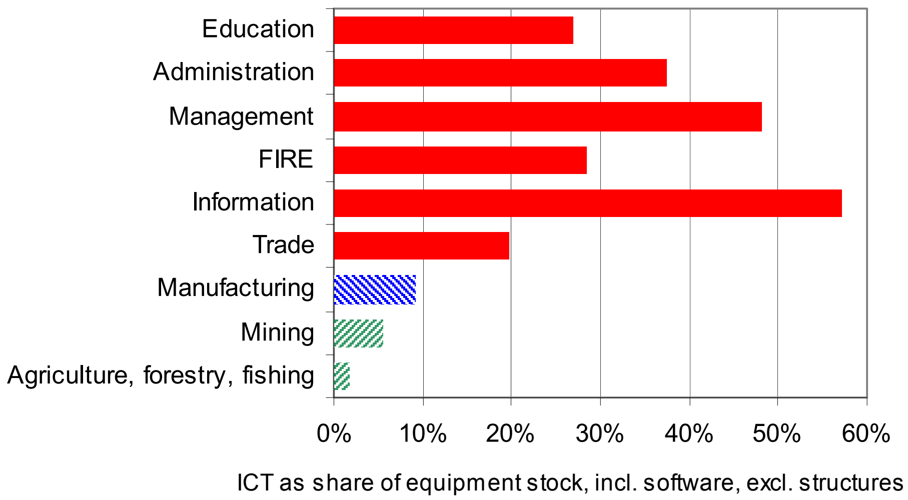
Productivity studies at the aggregate level are more important than industry- and firm-level studies. The dominance of aggregate-level studies can be gleaned from the fact that in 2003, *Amazon.com* (an online retailer) recorded profits of $30 million, yet global music industry profits declined by nearly $2.5 billion. According to music industry executives, the simultaneous creation of profits in the one industry and their destruction in the other is caused by internet music download and online piracy (Harford 2007:153).

Hence, computers are not everywhere, because ICT capital is concentrated in the services sector. The services sector is generally characterised by low productivity growth rates, a phenomenon referred to as Baumol’s unbalanced productivity hypothesis (Baumol 1967; Baumol, Blackman & Wolf 1985). McGuckin and Stiroh (1998:42, table 1) show that three service sectors are particularly intensive in the use of computers: trade; finance, insurance and real estate (FIRE); and other services, such as business and personal services (i.e. software, healthcare , legal services, etc.).

Figure 8.3 illustrates that the stock of ICT capital is concentrated in particular services industries (shown in red/solid).

Services sector activities are difficult to measure and a large body of research has probed these measurement problems, as explored in chapter 6. No consensus has as yet emerged: some researchers find that services productivity has recovered, but others that the recovery is simply based on old economy laws and competitive intensity.

Figure 8.3: ICT stock as a percentage of equipment stock (private nonresidential fixed assets) by industry (2002)



Source: BEA, National Economic Accounts, fixed asset tables. Note: FIRE = finance, insurance and real estate.

Some economists argue that IT is a transcendent technology that affects all other industries and drives overall economic growth (Kettell 2001:247). Thus ICT resembles the railroads in the nineteenth century and motorcars in the twentieth century. The computer revolution is regarded as the third industrial revolution.

8.8. Explanations of the paradox

Chapter 6 and 7 reviewed the explanations of the paradox, building on the conceptual tools developed in earlier chapters.

Chapter 6 probed the heart of the Solow paradox: the many measurement problems, particularly the measurement of quality change, and related issues, (such as hedonic indexes, intangible capital, factor income shares, services sector output, factor income shares and inflation measurement) that have emerged in the productivity paradox literature.

The Cambridge Controversy debates the aggregation problem and the validity of neoclassical theory in this regard, which presents a number of conceptual and theoretical problems.

The most convincing explanation of the paradox, the mismeasurement hypothesis, does not fully explain the Solow paradox, but only a small part of the productivity slowdown. Measurement errors are encountered routinely in many statistical analyses. The sudden decline in the productivity growth rate in 1973, however, cannot mean that the indexes should henceforth be rejected as unreliable. The claim that inadequate adjustments for quality in the indexes fundamentally tarnish the productivity statistics is argued to be exaggerated.

In chapter 7 the GPT hypothesis was reviewed, which boils down to an argument about the timing, i.e. the delayed impact, of ICT on output and productivity. The argument that IT "has become a competitive necessity, but not a source of competitive advantage" (Hitt & Brynjolfsson 1994:265) was put forward. This view was echoed by Carr (2003) in an influential article in the *Harvard Business Review* – subsequently turned into a book (Carr 2004) – that "IT doesn't matter".

The economics of ICT, examined in chapters 4 and 7, guided the interpretation that the rapid decline in computer prices propelled its substitution for other more expensive inputs and investments, so that "the economic impact of the computer is not a productivity story at all" (Triplett 1999b:314)! Stiroh (1998:175) and Jorgenson and Stiroh (1999:109) make the same point. The economic incentives for substitution by IT, provided by falling computer prices, have led to capital deepening, not invisible spillovers into various other industries (Jorgenson & Stiroh (2000b:186). Thus the differentiating effect of ICT on labour productivity (LP) compared to multifactor productivity (MFP) may resolve the Solow paradox (McGuckin & Stiroh 1998). The impact of computers can be seen in the accumulation of computer capital (i.e. capital deepening through substitution), but not in MFP (McGuckin & Stiroh 1998:48). Although LP revived somewhat after 1979, MFP remained sluggish. Growth in the computer-producing sector from 1979 to 1991 is attributable to MFP (McGuckin & Stiroh 1998:47).

The correct calculation of factor income shares is thus crucial to the assessment of the relative contribution of capital accumulation compared to productivity: a higher share of capital implies a lower contribution of TFP to economic growth.

Some authors have argued that intangible capital, which is largely excluded from the NIPAs, can account for the productivity slowdown. Corrado et al. (2006:1), after incorporating intangibles into the NIPAs (discussed in chapter 6), argue that the productivity data indeed started to show the computer revolution in the mid-1990s. The slowdown is therefore seen as a statistical mirage:

“computers are everywhere” if intangible capital is included. Similarly, if intangibles are counted as capital, the role of MFP in economic growth is reduced and capital deepening becomes the dominant cause (Corrado et al. 2006: abstract).

Solow’s later responses to the computer paradox were reviewed in chapter 7. The conclusion in this dissertation is consistent with Solow’s views and consistent with the productivity data in the NIPAs, namely that there has been some productivity revival, but that the paradox – which applies to the 1973 to 1995 period – largely remains unresolved.

Counterfactual research, discussed in chapter 7, may well prove to be a rewarding topic for future research into the computer paradox. It cannot be speculated here what such research, if ever conducted, would conclude, but counterfactual analysis of the impact of computerisation on productivity, would shed more light on this complex problem, if not help resolve the debate. It may well be consistent with Solow remarks that computers are not as productive as expected. Contrariwise, it could also be argued that if computers had not been invented, the productivity and growth slowdown might have been more severe – that is, the productivity and growth contribution of computers might be much greater than what the actual data show. Fogel’s (2004:9-10) arguments on the understatement of the true increase in the standard of living through the mismeasurement of quality change in the USA were reviewed in chapter 6. His optimistic opinion on the true level of living suggests that he might be in favour of this interpretation.

8.9. Final remarks

Brynjolfsson and Yang (1996:2) aptly described the productivity paradox as a clash of expectations and statistics, echoing Solow’s (1998:121) remarks (see chapter 7). The “new economy” enthusiasts raised expectations about a business future unconstrained by old economy laws. The enthusiasm of the “new economy” faithful and productivity optimists was dissipated by the collapse of the technology and new economy stocks in 2000. It is probably too early to tell if there is a “new economy’”(Stiroh 1999) and whether the recent productivity upsurge can be sustained. There is now more scepticism about the singular impact of computers on productivity.

Denison (1980b), a productivity pioneer, was perplexed by the productivity slowdown after 1973 and believed that it remains a mystery. He attributed the slowdown to a number of possible factors, each of which can only explain a small part of the decline. Denison’s prescient insight, formulated so soon after 1973, is endorsed by Gordon (1999b:123), who, a quarter century later, shares the view that single-cause explanations have failed. Many hypotheses have been put forward to explain the paradox, but no single account is entirely satisfactory; nor is there any kind of consensus on the computer paradox. The paradox was abandoned, not resolved, as Solow suggests.

The productivity paradox therefore leads back to Abramowitz's (1956:11) view, which referred to the productivity residual as "some sort of measure of our ignorance about the causes of economic growth". This characterisation was adopted by many other economists and is often repeated in the productivity literature.

Madrick (1998:61) argues as follows: "The irony is that the greatest machine as yet known to mankind, the computer, is creating, not reducing demand for the most human of capabilities, the human imagination."

It is human ingenuity, embodied in technical progress, and the advancement of knowledge, embodied in physical and human capital, which drives productivity and improvements in the standard of living. Computers fulfil a role in this advancement, but their extent and significance remain largely unresolved.

End.

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THE PRODUCTIVITY PARADOX: INFORMATION TECHNOLOGY AND PRODUCTIVITY

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